Part II - OFF-HIGHWAY MOBILE SOURCES

INTRODUCTION

This section contains emission rates for eight types of off-highway mobile sources. The emissions of six of these types of sources are unchanged from the previous edition and supplements. Changes have been made inboard powered vessels and diesel powered heavy-duty construction equipment. The changes for these two sources are summarized below.

Inboard Powered Vessels - Only one item has been changed since the previous edition. This change was the deletion of the 1550 horsepower diesel emission factors from Table II-3.3 because they were for a 1550 horsepower steam engine and not a diesel engine.

Construction Equipment - The emission factors for heavy-duty diesel construction equipment are based on a recent study by Environmental Research and Technology, Inc. Some of the categories of construction equipment have changed. The emission factors for heavy-duty gas powered construction equipment are the same as in the previous edition.

Comments on Other Studies - Recently there have been two studies undertaken for off-highway mobile sources. The first one deals strictly with inboard powered vessels, and is entitled "Emission Factor Documentation for AP-42: Section 3.2.3 Inboard Powered Vessels" (EPA 450/4-84-001). The second report discusses locomotives, construction equipment and inboard powered vessels, and is entitled "Recommended Revisions to Gaseous Emission Factors for Several Classes of Off-Highway Vehicles - Final Report" (EPA 460/3-85-004, March 1985). The following are EPA's comments on material presented in these reports relative to AP-42.

Locomotives - The current emission factors for locomotives are based on tests of three in-use locomotives. The second report located data on at least fifteen new locomotives, and recommended updating the emissions to this new data set. The report also suggested that the duty cycle for locomotives include some engine shut-down in place of some engine idle, mostly based on the fact that fuel costs are higher and companies would encourage engine shut-down as a cost saving measure. The previous emission factors do not assume any engine shut-down during the duty cycle. EPA has not adopted the new emission factors, and instead has retained the previous emission factors for two reasons. First, there does not appear to be any verifiable basis for picking the percent of engine shut-down time during the duty cycle. Second, EPA has become aware of a larger data set of in-use locomotives with emission data. EPA intends to analyze these data in the near future, and feels it would be inappropriate to update the locomotive emission factors with the fifteen locomotives on an interim basis, only to change them at a later date.

Inboard Powered Vessels - The first report compiled available data on inboard powered vessels and attempted to estimate the emission factors.

The second report critiqued the first report, and found some inconsistencies in the manner in which the emission factors were estimated. The second report recommended only two changes to the existing emission factors -- one was the removal of the 1550 horsepower emission rates from Table II-3.3. (This engine was a steam boiler, and not diesel powered as presented.) This we have done. The second was the addition of some new emission rates for diesel engines above 3000 horsepower, but at only one load setting and in units which were inconsistent with those in Table II-3.2. EPA investigated the possibility of converting the new data into the old units but had no basis for estimating the appropriate conversion factor. Therefore, the previous emission factors (at 3600 horsepower) are retained.

Future Work - Beside locomotives, EPA may also soon undertake a study of emissions from new aircraft. Emission standards for new aircraft took effect in 1984; therefore, all 1984 and newer aircraft should have lower emissions than the rates presented herein. However, the present emission rates for aircraft are sufficient for now, since the majority of aircraft in use are pre-1984 uncontrolled technology.

II-1 AIRCRAFT

II-1.1 General

Aircraft engines are of two major categories, reciprocating piston and gas turbine.

In the piston engine, the basic element is the combustion chamber, or cylinder, in which mixtures of fuel and air are burned and from which energy is extracted by a piston and crank mechanism driving a propeller. The majority of aircraft piston engines have two or more cylinders and are generally classified according to their cylinder arrangement - either "opposed" or "radial". Opposed engines are installed in most light or utility aircraft, and radial engines are used mainly in large transport aircraft. Almost no singlerow inline or V-engines are used in current aircraft.

The gas turbine engine usually consists of a compressor, a combustion chamber and a turbine. Air entering the forward end of the engine is compressed and then heated by burning fuel in the combustion chamber. The major portion of the energy in the heated air stream is used for aircraft propulsion. Part of the energy is expended in driving the turbine, which in turn drives the compressor. Turbofan and turboprop (or turboshaft) engines use energy from the turbine for propulsion, and turbojet engines use only the expanding exhaust stream for propulsion. The terms "propjet" and "fanjet" are sometimes used for turboprop and turbofan, respectively.

The aircraft in the following tables include only those believed to be significant at present or over the next few years.

Few piston engine aircraft data appear here. Military fixed wing piston aircraft, even trainers, are being phased out. One piston engine helicopter, the TH-55A "Osage", sees extensive use at one training base at Ft. Rucker, AL (EPA Region IV), but engine emissions data are not available. Most civil piston engine aircraft are in general aviation service.

The fact that a particular aircraft brand is not listed in the following tables does not mean the emission factors cannot be calculated. It is the engine emissions and the time-in-mode (TIM) category which determine emissions. If these are known, emission factors can be calculated in the same way that the following tables are developed.

The civil and military aircraft classification system used is shown in Tables II- 1-1 and II- 1-2. Aircraft have been classified by kind of aircraft and the most commonly used engine for that kind. Jumbo jets normally have a miximum of about 40,000 pounds thrust per engine, and medium range jets about 14,000 pounds thrust per engine. Small piston engines develop less than 500 horsepower.

II- 1.2 The Landing/Takeoff Cycle and Times-in-Mode

A landing/takeoff (LTO) cycle incorporates all of the normal flight and ground operation modes (at their respective times-in-mode), including: descent/approach from approximately 3000 feet (915 m) above ground level (AGL), touchdown, landing run, taxi in, idle and shutdown, startup and idle, checkout, taxi out, takeoff, and climbout to 3000 feet (915m) AGL.

In order to make the available data manageable, and to facilitate comparisons, all of these operations are conventionally grouped into five standard modes: approach, taxi/idle in, taxi/idle out, takeoff and climbout. There are exceptions. The supersonic transport (SST) has a descent mode preceding approach. Helicopters omit the takeoff mode. Training exercises involve "touch and go" practice. These omit the taxi/idle modes, and the maximum altitude reached is much lower. Hence, the duration (TIM) of the approach and climbout modes will be shorter.

Each class of aircraft has its own typical LTO cycle (set of TIMs). For major classes of aircraft, these are shown in Tables II- 1-3 and II- 1-4. The TIM data appearing in these tables should be used for guidance only and in the absence of specific observations. The military data are inappropriate to primary training. The civil data apply to large, congested fields at times of heavy activity.

All of the data assume a 3000 foot AGL inversion height and an average U.S. mixing depth. This may be inappropriate at specific localities and times, for which specific site and time inversion height data should be sought. Aircraft emissions of concern here are those released to the atmosphere below the inversion. If local conditions suggest higher or lower inversions, the duration (TIM) of the approach and climbout modes must be adjusted correspondingly.

A more detailed discussion of the assumptions and limitations implicit in these data appears in Reference 1.

Emission factors in Tables II- 1-9 and II- 1-10 were determined using the times-in-mode presented in Tables II- 1-3 and II- 1-4, and generally for the engine power settings given in Tables II- 1-5 and II- 1-6.

Table II-1-1. CIVIL AIRCRAFT CLASSIFICATION[a]

Aircraft	Engine[b]			
	No.	Mfg.	Type	Model/Series
Supersonic transport				
BAC/Aerospatiale Concorde	4	RR	TF	Olymp. 593-610
Short, medium, long range and jumbo jets				
BAC 111-400	2	RR	TF	Spey 511
Boeing 707-320B	4	P&W	TF	JT3D-7
Boeing 727-200	3	P&W	TF	JT8D-17
Boeing 737-200	2	P&W	TF	JT8D-17
Boeing 747-200B	4	P&W	TF	JT9D-7
Boeing 747-200B	4	P&W	TF	JT9D-70
Boeing 747-200B	4	RR	TF	RB211-524
Lockheed L1011-200	3	RR	TF	RB211-524
Lockheed L1011-100	3	RR	TF	RB211-22B
McDonnell-Douglas DC8-63	4	P&W	TF	JT3D-7
McDonnell-Douglas DC9-50	2	P&W	TF	JT8D-17
McDonnell-Douglas DC10-30	3	GE	TF	CF6-50C
Air carrier turboprops - commuter, feeder line and freighters				
Beech 99	2	PWC	TP	PT6A-28
GD/Convair 580	2	All	TP	501
DeHavilland Twin Otter	2	PWC	TP	PT6A-27
Fairchild F27 and FH227	2	RR	TP	R. Da. 7
Grumman Goose	2	PWC	TP	PT6A-27
Lockheed L188 Electra	4	All	TP	501
Lockhead L100 Hercules	4	All	TP	501
Swearingen Metro-2	2	GA	TP	TPE 331-3
Business jets				
Cessna Citation	2	P&W	TF	JT15D-1
Dassault Falcon 20	2	GE	TF	CF700-2D
Gates Learjet 24D	2	GE	TJ	CJ610-6
Gates Learjet 35, 36	2	GE	TF	TPE 731-2
Rockwell International Shoreliner 75A	2	GE	TF	CF 700
Business turboprops (EPA Class P2)				
Beech B99 Airliner	2	PWC	TP	PT6A-27
DeHavilland Twin Otter	2	PWC	TP	PT6A-27
Shorts Skyvan-3	2	GA	TP	TPE-331-2
Swearingen Merlin IIIA	2	GA	TP	TPE-331-3
General aviation piston (EPA Class P1)				
Cessna 150	1	Con	O	0-200
Piper Warrior	1	Lyc	O	0-320
Cessna Pressurized Skymaster	2	Con	O	TS10-360C
Piper Navajo Chieftain	2	Lyn	O	T10-540

[a] References 1 and 2.
[b] Abbreviations: TJ - tubojet, TF - turbofan, TP - turboprop, R - reciprocating piston, O - opposed piston. All - Detroit Diesel Allison Division of General Motors, Con - Teledyne/Continental, GA - Garrett AiResearch, GE - General Electric, Lyc - Avco/Lycoming, P&W - Pratt & Whitney, PWC - Pratt & Whitney Aircraft of Canada, RR - Rolls Royce.

Table II-1-2. MILITARY AIRCRAFT CLASSIFICATION[a]

Aircraft mission (Class)	DOD Designation	Popular name	Manufacturer[b]	Service	Power plant No. & Type[c]		Mfg.[b]	Designation
Combat	A-4	Skyhawk	McD-Doug	USN, USMC	1	TJ	P&W	J52, J65
	A-7	Corsair 2	Vought	USN	1	TF	All, P&W	TF41, TF30
	F-4	Phantom 2	McD-Doug	USAF, USN	2	TJ	GE	J79
	F-5	Freedom Fighter/ Tiger 2	Northrop	USAF	2	TJ	GE	J85
	F-14	Tomcat	Grumman	USN	2	TF	P&W	TF30, F401
	F-15A	Eagle	McD-Doug	USAF	2	TF	P&W	F100
	F-16	-	GD/FW	USAF	1	TF	P&W	F100
Bomber	B-52	Stratofortress	Boeing	USAF	8	TJ, TF	P&W	J57, TF33
Transport Patrol/Antisub	C-5A	Galaxy	GELAC	USAF	4	TF	GE	TF39
	C-130	Hercules	GELAC	USAF, USN, USCG	4	TP	All	T56
	KC-135	Stratotanker	Boeing	USAF	4	TJ	P&W	J57
	C-141	Starlifter	GELAC	USAF	4	TF	P&W	TF33
	P-3C	Orion	CALAC	USN	4	TP	All	T56
	S-3A	Viking	CALAC	USN	2	TF	GE	TF34
Trainer	T-34C	Turbo Mentor	Beech	USN	1	TP	PWC	PT6A
	T-38	Talon	Northrop	USAF	2	TJ	GE	J85
Helicopter	UH-1H	Iroquois/Huey	Bell	USA, USN	1	TS	Lyc, GE	T53, T58
	HH-3	Sea King/Jolly Green Giant	Sikorsky	USAF, USN, USCG	2	TS	GE	T58
	CH-47	Chinook	Boeing Vertol	USA	2	TS	Lyc	T55

[a] Reference 1. USN - U.S. Navy, USMC - U.S. Marine Corps, USAF - U.S. Air Force, USCG - U.S. Coast Guard, USA - U.S. Army.
[b] Abbreviations: All - Detroit Diesel Allison Division of General Motors, CALAC - Lockheed - California, GD/FW - General Dynamics, Ft. Worth, GE - General Electric, GELAC - Lockheed-Georgia, Lyc - Lycoming, McD-Doug - McDonnell Douglas, P&W - Pratt & Whitney, PWC - Pratt & Whitney Aircraft of Canada.
[c] TJ - Turbojet, TF - Turbofan, TP - Turboprop, TS - Turboshaft.

Table II-1-3. TYPICAL DURATION FOR CIVIL LTO CYCLES AT LARGE CONGESTED METROPOLITAN AIRPORTS[a]

Aircraft	Mode					
	Taxi/ Idle out	Takeoff	Climbout	Approach	Taxi/ Idle in	Total
Commercial carrier						
Jumbo, long and medium range jet[b]	19.0	0.7	2.2	4.0	7.0	32.9
Turboprop[c]	19.0	0.5	2.5	4.5	7.0	33.5
Transport-piston	6.5	0.6	5.0	4.6	6.5	23.2
General aviation						
Business jet	6.5	0.4	0.5	1.6	6.5	15.5
Turboprop[c]	19.0	0.5	2.5	4.5	7.0	33.5
Piston[d]	12.0	0.3	5.0	6.0	4.0	27.3
Helicopter	3.5	-	6.5	6.5	3.5	20.0

[a] Reference 3. Data given in minutes.
[b] Same times as EPA Classes T2, T3 and T4 (Note b, Table II-1-5).
[c] Same times as EPA Classes T1 and P2 (Note b, Table II-1-5).
[d] Same times as EPA Class P1 (Note b, Table II-1-5).

Table II-1-4. TYPICAL DURATION FOR MILITARY LTO CYCLES[a]

Aircraft	TIM[b] Code	Mode					
		Taxi/ Idle out	Takeoff	Climbout	Approach	Taxi/ Idle in	Total
Combat[c]							
USAF	1	18.5	0.4	0.8	3.5	11.3	34.5
USN[d]	2	6.5	0.4	0.5	1.6	6.5	15.5
Trainer - Turbine							
USAF T-38	3	12.8	0.4	0.9	3.8	6.4	24.3
USAF general	4	6.8	0.5	1.4	4.0	4.4	17.1
USN[d]	2	6.5	0.4	0.5	1.6	6.5	15.5
Transport - Turbine[e]							
USAF general	5	9.2	0.4	1.2	5.1	6.7	22.6
USN[f]	6	19.0	0.5	2.5	4.5	7.0	33.5
USAF B-52 and KC-135	7	32.8	0.7	1.6	5.2	14.9	55.2
Military - Piston	8	6.5	0.6	5.0	4.6	6.5	23.2
Military - Helicopter	9	8.0	-	6.8	6.8	7.0	28.6

[a]Reference 1. Data given in minutes. USAF - U.S. Air Force, USN - U.S. Navy.
[b]TIM Code defined in Table II-1-5.
[c]Fighters and attack craft only.
[d]Time-in-mode is highly variable. Taxi/idle out and in times as high as 25 and 17 minutes, respectively, have been noted. Use local data base if possible.
[e]Includes all turbine craft not specified elsewhere (i.e., transport, cargo, observation, patrol, antisubmarine, early warning, and utility).
[f]Same as EPA Class P2 for civil turboprops.

Table II-1-5. ENGINE POWER SETTINGS FOR TYPICAL EPA LTO COMMERCIAL CYCLES[a]

Mode	Power setting (% thrust or horsepower)			
	Class T1, P2[b]	Class T2,T3, T4[b]	Class P1[b]	Helicopter
Taxi/Idle (out)	Idle	Idle	Idle	
Takeoff	100	100	100	
Climbout	90	85	75 - 100	Undefined
Approach	30	30	40	
Taxi/Idle (in)	Idle	Idle	Idle	

[a]References 1 and 3.
[b]As defined by EPA (Reference 3):

Class T1 is all aircraft turbofan or turbojet engines except Class T5 of rated power less than 8000 lbs thrust.

Class T2 is all turbofan or turbojet aircraft engines except Classes T3, T4 and T5 of rated power of 8000 lbs thrust or greater.

Class T3 is all aircraft gas turbine engines of the JT3D model family.

Class T4 is all aircraft gas turbine engines of the JT8D model family.

Class T5 is all aircraft gas turbine engines on aircraft designed to operate at supersonic speeds.

Class P1 is all aircraft piston engines, except radial.

Class P2 is all aircraft turboprop engines.

Table II-1-6. ENGINE POWER SETTINGS FOR A TYPICAL LTO MILITARY CYCLE[a]

Mode	Power setting (% thrust or horsepower)			
	Military transport	Military jet	Military piston	Military helicopter
Taxi/Idle (out)	Idle	Idle	5 - 10	Idle
Takeoff	Military	Military or Afterburner	100	-
Climbout	90 - 100	Military	75	60 - 75
Approach	30	84 - 86	30	45 - 50
Taxi/Idle (in)	Idle	Idle	5 - 10	Idle

[a] Reference 1.

TABLE II-1-7. MODAL EMISSION RATES–CIVIL AIRCRAFT ENGINES[a]

Model-Series Mfg[b] Type[b]	Mode	Fuel Rate lb/hr	Fuel Rate kg/hr	CO lb/hr	CO kg/hr	NO_x[c] lb/hr	NO_x[c] kg/hr	Total HC[d] lb/hr	Total HC[d] kg/hr	SO_x[e] lb/hr	SO_x[e] kg/hr	Particulates[f] lb/hr	Particulates[f] kg/hr
250B17B All. TP	Idle	63	28.58	6.13	2.78	0.09	0.041	1.27	0.576	0.06	0.03		
	Takeoff	265	120.2	2.07	0.939	1.75	0.794	0.07	0.032	0.27	0.12		
	Climbout	245	111.1	2.21	1.00	1.46	0.662	0.09	0.041	0.25	0.11		
	Approach	85	38.56	4.13	1.87	0.19	0.086	0.44	0.200	0.09	0.04		
501D22A All. TP	Idle	610	276.7	26.60	12.07	2.15	0.975	10.74	4.87	0.61	0.28		
	Takeoff	2376	1078	4.85	2.20	21.10	9.57	0.67	0.304	2.38	1.08		
	Climbout	2198	997	4.53	2.05	20.27	9.19	1.96	0.889	2.20	1.00		
	Approach	1140	517.1	5.81	2.64	8.54	3.87	2.23	1.01	1.14	0.52		
TPE 331-3 GA TP	Idle	112.0	50.8	6.89	3.12	0.320	0.145	8.86	4.02	0.11	0.05	0.3[g]	0.14[g]
	Takeoff	458.0	207.7	0.350	0.159	5.66	2.57	0.050	0.023	0.46	0.21	0.8	0.36
	Climbout	409.0	185.5	0.400	0.181	4.85	2.20	0.060	0.027	0.41	0.19	0.6	0.27
	Approach	250.0	113.4	1.74	0.789	2.48	1.12	0.160	0.073	0.25	0.11	0.6	0.27
TPE331-2 GA TP	Idle	105.0	47.6	6.73	3.05	0.27	0.22	9.58	4.34	0.11	0.05	(Assume 331-3 data)	
	Takeoff	405.0	183.7	0.38	0.172	4.14	1.88	0.16	0.072	0.41	0.18		
	Climbout	372.0	168.7	0.51	0.231	3.69	1.67	0.15	0.068	0.37	0.17		
	Approach	220.0	99.8	3.65	1.66	1.82	0.826	0.59	0.268	0.22	0.10		
TPE 731-2 GA TF	Idle	181.0	82.1	11.11	5.04	0.54	0.245	4.05	1.84	0.18	0.08		
	Takeoff	1552.0	704.0	1.86	0.844	29.8	13.52	0.14	0.064	1.55	0.70		
	Climbout	1385.0	628.2	1.80	0.816	23.68	10.74	0.12	0.054	1.39	0.63		
	Approach	521.0	236.3	9.53	4.32	3.59	1.63	1.51	0.685	0.52	0.24		
CJ 610-2C GE TJ	Idle	510.0	231.3	79.05	35.86	0.46	0.209	9.18	4.16	0.51	0.23		
	Takeoff	2780.0	1261.0	75.06	34.05	11.68	5.30	0.28	0.127	2.78	1.26		
	Climbout	2430.0	1102.0	65.61	29.76	8.99	4.08	0.49	0.222	2.43	1.10		
	Approach	1025.0	464.9	90.20	40.91	1.54	0.698	2.77	1.26	1.03	0.46		
CF700-2D GE TF	Idle	460	208.7	71.30	32.34	0.41	0.186	8.28	3.76	0.46	0.21		
	Takeoff	2607	1182	57.35	26.01	14.60	6.62	0.26	0.118	2.61	1.18		
	Climbout	2322	1053	58.05	26.33	9.98	4.53	0.23	0.104	2.32	1.05		
	Approach	919	416.9	56.98	25.85	1.65	0.748	1.29	0.585	0.92	0.42		
CF6-6D GE TF	Idle	1063	482.2	65.06	29.51	4.88	2.21	21.79	9.88	1.06	0.48	0.04[g]	0.02[g]
	Takeoff	13750	6237	8.25	3.74	467.5	212.1	8.25	3.74	13.75	6.24	0.54	0.24
	Climbout	11329	5139	6.80	3.03	309.2	140.2	6.80	3.08	11.33	5.14	0.54	0.24
	Approach	3864	1753	23.18	10.51	41.54	18.84	6.96	3.16	3.86	1.75	0.44	0.20
CF6-50C GE TF	Idle	1206	547	88.04	39.93	3.02	1.37	36.18	16.41	1.21	0.55	(Assume CF6-6D data)	
	Takeoff	18900	8573	0.38	0.172	670.95	304.3	0.19	0.086	18.90	8.57		
	Climbout	15622	7104	4.70	2.13	462.0	209.6	0.16	0.073	15.62	7.10		
	Approach	5280	2395	22.70	10.30	52.8	23.95	0.05	0.023	5.28	2.40		

TABLE II-1-7 (CONTINUED)

Model-Series Mfg[b] Type[b]	Mode	Fuel Rate lb/hr	Fuel Rate kg/hr	CO lb/hr	CO kg/hr	NO_x[c] lb/hr	NO_x[c] kg/hr	Total HC[d] lb/hr	Total HC[d] kg/hr	SO_x[e] lb/hr	SO_x[e] kg/hr	Particulates[f] lb/hr	Particulates[f] kg/hr
JT3D-7 P&W TF	Idle	1013	459.5	140.8	63.87	2.23	1.01	124.6	56.52	1.01	0.46	0.45[g]	0.20[g]
	Takeoff	9956	4516	8.96	4.06	126.4	57.34	4.98	2.26	9.96	4.52	8.25	3.7
	Climbout	8188	3714	15.56	7.06	78.6	35.65	3.28	1.49	8.19	3.71	8.5	3.9
	Approach	3084	1399	60.14	27.28	16.35	7.42	6.48	2.94	3.08	1.40	8.0	3.6
JT8D-17 P&W TF	Idle	1150	521.6	39.10	17.74	3.91	1.77	10.10	4.58	1.15	0.52	0.36[g,h]	0.16[g,h]
	Takeoff	9980	4527	6.99	3.17	202.6	91.90	.50	0.227	9.98	4.53	3.7	1.7
	Climbout	7910	3588	7.91	3.59	123.4	55.97	.40	0.181	7.91	3.59	2.6	1.2
	Approach	2810	1275	20.23	9.18	19.39	8.80	1.41	0.640	2.81	1.28	1.5	0.68
JT9D-7 P&W TF	Idle	1849	838.7	142.4	64.59	5.73	2.60	55.10	24.99	1.85	0.84	2.2[f]	1.0
	Takeoff	16142	7322	3.23	1.47	474.6	215.3	0.81	0.367	16.14	7.32	3.75	1.7
	Climbout	13193	5984	6.60	2.99	282.3	128.0	1.32	0.599	13.19	5.98	4.0	1.8
	Approach	4648	2108	44.62	20.24	36.25	16.44	4.65	2.11	4.65	2.11	2.3	1.0
JT9D-70 P&W TF	Idle	1800	816.5	61.20	27.76	5.76	2.61	12.24	0.55	1.80	0.82		
	Takeoff	19380	8791	3.88	1.76	600.8	272.5	2.91	1.32	19.38	8.79	(assume JT9D-7 data)	
	Climbout	15980	7248	4.79	2.17	386.7	175.4	2.40	1.09	15.98	7.25		
	Approach	5850	2654	7.61	3.45	47.39	21.50	2.63	1.19	5.85	2.65		
JT15D-1 PWC TF	Idle	215	97.52	19.46	8.83	0.54	0.245	7.48	3.39	0.22	0.10		
	Takeoff	1405	637.3	1.41	0.640	14.19	6.44	0	0	1.41	0.64		
	Climbout	1247	565.6	1.25	0.567	11.35	5.15	0	0	1.25	0.57		
	Approach	481	218.2	11.45	5.19	2.45	1.11	1.59	0.721	0.48	0.22		
PT6A-27 PWC TP	Idle	115	52.16	7.36	3.34	0.28	0.127	5.77	2.62	0.12	0.05		
	Takeoff	425	192.8	0.43	0.195	3.32	1.51	0	0	0.43	0.19		
	Climbout	400	181.4	0.48	0.218	2.80	1.27	0	0	0.40	0.18		
	Approach	215	97.52	4.95	2.24	1.80	0.816	0.47	0.213	0.22	0.10		
PT6A-41 PWC TP	Idle	147	66.63	16.95	7.69	0.29	0.132	14.94	6.78	0.15	0.07		
	Takeoff	510	231.3	2.60	1.18	4.07	1.85	0.89	0.404	0.51	0.23		
	Climbout	473	214.6	3.07	1.39	3.58	1.62	0.96	0.435	0.47	0.21		
	Approach	273	123.8	9.50	4.31	1.27	0.576	6.20	2.81	0.27	0.12		
Spey 555-15[i] RR TF	Idle	915	415	83.2	37.7	1.6	0.7	86.0	43.5	0.92	0.42		
	Takeoff	5734	2600	6.5	3.0	109.2	49.5	29.5	13.4	5.73	2.60		
	Climbout	4677	2121	0.0	0.0	68.7	31.2	2.5	1.1	4.68	2.12		
	Approach	1744	791	34.8	15.8	10.2	4.6	14.3	6.5	1.74	0.79		
Spey MK511[g,i] RR TF	Idle	946	429.1	104.4	47.36	0.785	0.356	80.03	36.30	0.95	0.43	0.17	0.077
	Takeoff	7057	3201	16.16	7.33	156.7	71.08	13.97	6.34	7.06	3.20	16.0	7.3
	Climbout	5752	2609	0.0	0.0	116.8	52.98	0.0	0.0	5.75	2.61	10.0	4.5
	Approach	2204	999.7	48.71	22.09	16.00	7.26	20.56	9.33	2.20	1.00	1.5	0.68
M45H-01[i] RR (Bristol) TF	Idle	366	166.0	55.63	25.23	0.622	0.282	11.53	5.23	0.37	0.17		
	Takeoff	3590	1628	7.18	3.26	32.31	14.66	0.718	0.326	3.59	1.62		
	Climbout	3160	1433	9.48	4.30	25.28	11.47	0.632	0.287	3.16	1.43		
	Approach	1067	484.0	53.56	24.29	3.57	1.62	6.61	3.00	1.07	0.48		

TABLE II-1-7 (CONTINUED)

Model-Series Mfg.[b] Type[b]	Mode	Fuel Rate lb/hr	Fuel Rate kg/hr	CO lb/hr	CO kg/hr	NO_x[c] lb/hr	NO_x[c] kg/hr	Total HC[d] lb/hr	Total HC[d] kg/hr	SO_x[e] lb/hr	SO_x[e] kg/hr	Particulates[f] lb/hr	Particulates[f] kg/hr
RB-211-22B[i] RR TF	Idle	1718	779.3	137.6	64.42	5.31	2.41	100.1	45.36	1.72	0.78		
	Takeoff	14791	6709	5.62	2.55	504.1	228.7	29.14	13.22	14.79	6.71		
	Climbout	12205	5536	14.89	6.75	301.9	136.9	8.30	3.76	12.21	5.54		
	Approach	4376	1985	93.78	42.54	32.26	14.63	32.16	14.59	4.38	1.99		
RB-211-524[i] RR TF	Idle	1769	802.4	35.91	16.29	4.74	2.15	5.43	2.46	1.77	0.80		
	Takeoff	17849	8096	7.32	3.32	660.4	299.6	1.96	0.889	17.85	8.10		
	Climbout	14688	6662	7.34	3.33	470.0	213.2	2.50	1.13	14.69	6.67		
	Approach	5450	2472	11.72	5.32	62.89	28.53	0.545	0.247	5.45	2.47		
RB-401-06[i] RR TF	Idle	330	149.7	10.07	4.57	0.825	0.374	0.924	0.419	0.33	0.15		
	Takeoff	2400	1089	2.40	1.09	30.0	13.61	0.120	0.054	2.40	1.09		
	Climbout	2130	966.2	2.77	1.26	24.07	10.92	0.107	0.049	2.13	0.97		
	Approach	775	351.5	5.04	2.29	3.88	1.76	0.155	0.070	0.78	0.35		
Dart RDa7[i] RR TP	Idle	411	186.4	37.61	17.06	0.292	0.132	25.52	11.58	0.41	0.19		
	Takeoff	1409	639.1	4.79	2.17	8.51	3.86	8.75	3.97	1.41	0.64		
	Climbout	1248	566.1	4.26	1.93	5.55	2.52	2.15	0.975	1.25	0.57		
	Approach	645	292.6	21.48	9.74	0.568	0.258	0.0	0.0	0.65	0.29		
Tyne[g,i] RR TP	Idle	619	280.8	40.79	18.50	0.477	0.216	6.63	3.01	0.62	0.28		
	Takeoff	2372	1076	1.21	0.549	27.11	12.30	2.87	1.31	2.37	1.08		
	Climbout	2188	922.5	1.29	0.585	25.23	11.44	2.63	1.19	2.19	0.99		
	Approach	1095	496.7	11.30	5.13	9.00	4.08	2.68	1.22	1.10	0.50		
Olympus 593[i] MK610 RR (Bristol) TJ	Idle	3060	1388	342.7	155.4	9.72	4.41	119.3	54.11	3.06	1.39		
	Takeoff	52200	23673	1513.8	686.5	542.9	246.2	151.4	68.7	52.2	23.7		
	Climbout	19700	8936	275.8	125.1	169.4	76.84	31.52	14.30	19.70	8.94		
	Descent	5400	2449	426.6	193.5	18.9	8.6	132.3	60.0	5.4	2.4		
	Approach	9821	4455	451.8	204.9	41.25	18.71	93.30	42.32	9.82	4.46		
O-200 Con. O	Idle	8.24	3.75	5.31	2.42	0.013	0.006	0.239	0.107	0.0	0		
	Takeoff	45.17	20.53	44.0	20.0	0.220	0.100	0.940	0.427	0.01	0		
	Climbout	45.17	20.53	44.0	20.0	0.220	0.100	0.940	0.427	0.01	0		
	Approach	25.50	11.59	30.29	13.75	0.029	0.013	0.847	0.385	0.01	0		
TSIO-360C Con. O	Idle	11.5	5.21	6.81	3.09	0.022	0.009	1.59	0.723	0.0	0.0		
	Takeoff	133.	60.3	143.9	65.3	0.36	0.16	1.22	0.55	0.03	0.01		
	Climbout	99.5	45.1	95.6	43.4	0.43	0.20	0.95	0.43	0.02	0.01		
	Approach	61.0	27.7	60.7	27.5	0.23	0.10	0.69	0.31	0.01	0.01		
6-285-B (Tiara) Con. O	Idle	72.12	10.03	26.23	11.90	0.0334	0.0152	0.773	0.350	0.0	0.0		
	Takeoff	153.0	69.39	152.7	69.3	0.899	0.408	1.78	0.806	0.03	0.01		
	Climbout	166.0	52.61	110.9	50.3	0.913	0.414	1.39	0.632	0.02	0.01		
	Approach	83.5	37.88	85.39	38.77	0.394	0.179	1.343	0.609	0.02	0.01		

TABLE II-1-7 (CONCLUDED)

Model-Series Mfg.[b] Type[b]	Mode	Fuel Rate lb/hr	Fuel Rate kg/hr	CO lb/hr	CO kg/hr	NO_x[c] lb/hr	NO_x[c] kg/hr	Total HC[d] lb/hr	Total HC[d] kg/hr	SO_x[e] lb/hr	SO_x[e] kg/hr	Particulate[f] lb/hr	Particulate[f] kg/hr
O-320 Lyc. O	Idle	9.48	4.30	10.21	4.63	0.0049	0.0022	0.350	0.159	0.0	0.0		
	Takeoff	89.1	40.4	96.0	43.5	0.195	0.088	1.05	0.475	0.02	0.01		
	Climbout	66.7	30.3	66.0	29.9	0.265	0.120	0.826	0.375	0.01	0.01		
	Approach	46.5	21.1	56.8	25.8	0.044	0.020	0.895	0.406	0.01	0.0		
IO-320-DIAD Lyc. O	Idle	7.84	3.56	4.86	2.20	0.009	0.0041	0.283	0.128	0.0	0.0		
	Takeoff	91.67	41.57	109.3	49.55	0.167	0.0756	1.047	0.475	0.02	0.01		
	Climbout	61.42	27.85	54.55	24.74	0.344	0.156	0.588	0.267	0.01	0.01		
	Approach	37.67	17.08	35.57	16.13	0.128	0.058	0.460	0.208	0.01	0.0		
IO-360-B Lyc. O	Idle	8.09	3.68	7.26	3.29	0.0094	0.0042	0.398	0.180	0.0	0.0		
	Takeoff	103.0	46.7	123.5	56.0	0.205	0.093	1.03	0.469	0.02	0.01		
	Climbout	71.7	32.5	70.5	32.0	0.329	0.149	0.585	0.265	0.01	0.01		
	Approach	36.6	16.6	25.3	11.5	0.372	0.169	0.355	0.161	0.01	0.0		
TIO-540-J2B2 Lyc. O	Idle	25.06	11.36	32.42	14.70	0.0097	0.0044	1.706	0.774	0.01	0.0		
	Takeoff	259.7	117.8	374.5	169.8	0.094	0.043	3.21	1.46	0.05	0.02		
	Climbout	204.5	92.7	300.8	136.4	0.0481	0.0218	3.40	1.54	0.04	0.02		
	Approach	99.4	45.1	125.4	56.9	0.138	0.0623	1.33	0.604	0.02	0.01		

[a]References 1,2.

[b]Abbreviations: All – Detroit Diesel Allison Division of General Motors; Con – Teledyne/Continental; GA – Garrett AiResearch; GE – General Electric; Lyc – Avco/Lycoming; P&W – Pratt & Whitney; PWC – Pratt & Whitney Aircraft of Canada; RR – Rolls Royce; TJ – Turbojet; TF – Turbofan; TP – Turboprop; O – Reciprocating (Piston) Opposed.

[c]Nitrogen oxides reported as NO_2.

[d]Total hydrocarbons. Volatile organics, including unburned hydrocarbons and organic pyrolysis products.

[e]Sulfur oxides and sulfuric acid reported as SO_2. Calculated from fuel rate and 0.05 wt% sulfur in Jet A and Jet B fuel, or 0.01 wt% sulfur in aviation gasoline. For turbine engines, the conversion is therefore SO_x (lb/hr) = 10^{-3} (fuel rate), and for piston engines, the conversion is SO_x (lb/hr) = 2×10^{-4} (fuel rate).

[f]All particulate data are from Reference 4. Does not include condensible compounds.

[g]The indicated reference does not specify series number for this model engine.

[h]"Diluted smokeless" JT 8D. Note: JT8D is a turbofan engine and is not equivalent to the *JT8 (Military J52) turbojet engine.*

[i]All Rolls Royce data are based upon an arbitrary 7% idle, which does not reflect the actual situation. In reality, Rolls Royce engines will idle at 5-6% with correspondingly higher emissions (Reference 2).

[j]The Olympus 593 engine used in the Concorde SST has a unique 6-mode LTO cycle.

TABLE II-1-8. MODAL EMISSION RATES – MILITARY AIRCRAFT ENGINES[a]

Model-Series (Civil Version) Mfgh Type[h]	Mode	Fuel Rate		CO		NO_x[b]		Total HC[c]		SO_x[d]		Particulates[e,f]	
		lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr
J57-P-22 (JT3C) P&W TJ	Idle	1087	493	64.4	29.2	2.7	1.2	55.8	25.3	1.1	0.5	8.3	3.8
	Takeoff	8358	3791	14.9	6.8	93.3	42.3	5.4	2.4	8.4	3.8	12.0	5.4
	Climbout	8358	3791	14.9	6.8	93.3	42.3	5.4	2.4	8.4	3.8	12.0	5.4
	Approach	1693	768	39.8	18.1	5.0	2.3	21.0	9.5	1.7	0.8		
J65-W-20 Wr. TJ	Idle	1333	605	66.9	30.3	3.7	1.7	5.0	2.3	1.3	0.6		
	Takeoff	6421	2913	49.6	22.5	48.5	22.0	0.2	0.1	6.4	2.9		
	Climbout	6421	2913	49.6	22.5	48.5	22.0	0.2	0.1	6.4	2.9		
	Approach	3260	1479	52.6	23.9	23.7	10.8	0.9	0.4	3.3	1.5		
J79-GE-10 GE TJ	Idle	1100	499	48.0	21.8	3.2	1.5	9.8	4.4	1.1	0.5	57.8	26.2
	Takeoff	35390	16053	611.9	277.6	241.3	109.5	17.2	7.8	35.4	16.1	299.7	135.9
	Climbout	9880	4482	52.0	23.6	151.8	68.9	16.0	7.3	9.9	4.5	77.7	35.2
	Approach	6190	2808	45.6	20.7	69.9	31.7	4.1	1.9	6.2	2.8	67.0 (nom)	30.4
J85-GE-5F GE TJ for T38	Idle	524	328	93.3	42.3	0.7	0.3	15.7	7.1	0.5	0.2		
	Takeoff	8470	3942	245.6	111.4	22.0	10.0	6.8	3.1	8.5	3.9		
	Climbout	1297	588	55.8	25.3	3.0	1.4	4.5	2.0	1.3	0.6		
	Approach	1098	498	63.7	28.9	3.0	1.4	1.3	0.6	1.1	0.5		
J85-GE-21 GE TJ for F-5	Idle	400	181	63.6	28.4	0.5	0.2	9.7	4.4	0.4	0.2		
	Takeoff	10650	4831	387.7	175.8	59.6	27.0	1.1	0.5	10.7	4.9		
	Climbout	3200	1452	69.0	31.3	16.0	7.3	0.8	0.4	3.2	1.5		
	Approach	1200	544	55.5	25.1	3.5	1.6	3.1	1.4	1.2	0.5		
TF30-P-6B (JTF 10) P&W TF for A-7	Idle	689	313	47.0	21.3	0.9	0.4	12.9	5.9	0.7	0.3		
	Takeoff	6835	3100	21.1	9.6	82.3	37.3	6.9	3.1	6.8	3.1		
	Climbout	6835	3100	21.1	9.6	82.3	37.3	6.9	3.1	6.8	3.1		
	Approach	3550	1610	22.4	10.2	23.7	10.8	10.5	4.8	3.6	1.6		
TF30-P-412A (JTF 10A) P&W TJ for F-14	Idle	999	453	68.1	30.9	2.4	1.1	38.4	17.4	1.0	0.5	26.5	12.0
	Takeoff	40000	18144	600.0	272.2	270.0	122.5	40.0	18.1	40.0	18.1	693.2	314.4
	Climbout	7394	3354	15.7	7.1	123.2	55.9	0.7	0.3	7.4	3.4	61.7	29.0
	Approach	2598	1178	39.5	17.9	18.4	8.3	2.9	1.3	2.6	1.2	46.6 (nom)	21.2
TF33-P-3/5/7 (JT3D) P&W TJ	Idle	846	384	74.9	34.0	1.5	0.7	77.8	35.3	0.8	0.4	4.4	2.0
	Takeoff	9979	4526	13.0	5.9	109.8	49.8	3.0	1.4	10.0	4.5	79.8	36.2
	Climbout	7323	3322	13.2	6.0	65.9	29.9	2.9	1.3	7.3	3.3	102.5	46.5
	Approach	3797	1722	34.2	15.5	27.7	12.6	14.4	6.5	3.8	1.7	53.1	24.1
TF34-GE-400 GE TJ	Idle	457	207	35.0	15.9	0.6	0.3	7.1	3.2	0.5	0.2		
	Takeoff	3796	1722	9.3	4.2	20.9	9.5	1.6	0.7	3.8	1.7		
	Climbout	3796	1722	9.3	4.2	20.9	9.5	1.6	0.7	3.8	1.7		
	Approach	1296	588	19.4	8.8	10.0	4.5	0.8	0.4	1.3	0.6		

TABLE II-1-8 (CONCLUDED)

Model-Series (Civil-Version) Mfg[h] Type[h]	Mode	Fuel Rate		CO		NO[b]		Total HC[c]		SO_x[d]		Particulates[e,f]	
		lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr
TF39-GE-1	Idle	1130	513	75.7	34.3	3.4	1.5	26.0	11.8	1.1	0.5	0.3[g]	0.1
(JT4A)	Takeoff	11410	5176	8.0	3.6	319.5	144.9	2.3	1.0	11.4	5.2	17.1[g]	7.8
GE TJ	Climbout	5740	2604	4.0	1.8	160.7	72.9	1.1	0.5	5.7	2.6	8.0[g]	3.6
	Approach	5740	2604	4.0	1.8	160.7	72.9	1.1	0.5	5.7	2.6	8.0[g]	3.6
TF41-A-2	Idle	1070	485	114.6	52.0	1.4	0.6	70.8	32.1	1.1	0.5		
All. TF	Takeoff	9040	4101	14.4	6.5	201.4	91.4	5.3	2.4	9.0	4.1		
	Climbout	9040	4101	14.4	6.5	201.4	91.4	5.3	2.4	9.0	4.1		
	Approach	5314	2410	27.5	12.5	56.6	25.7	12.9	5.9	5.3	2.4		
F100-PW-100	Idle	1060	481	20.5	9.3	4.2	1.9	2.4	1.1	1.1	0.5	0.1[g]	0.05
(JTF 22)	Takeoff	44200	20049	2435.4	1104.7	729.3	330.8	4.4	2.0	44.2	20.0	0.0[g]	0.0
P&W TF	Climbout	10400	4717	18.7	8.5	457.6	207.6	0.5	0.2	10.4	4.7	8.6[g]	3.9
	Approach	3000	1361	9.0	4.1	33.0	15.0	1.8	0.8	3.0	1.4	1.0[g]	0.5
PT6A-27	Idle	115	52	7.36	3.34	0.28	0.13	5.77	2.62	0.12	0.05		
PWC TP	Takeoff	425	193	0.43	0.20	3.32	1.51	0	0	0.43	0.20		
	Climbout	400	181	0.48	0.22	2.80	1.27	0	0	0.40	0.18		
	Approach	215	98	5.0	2.24	1.80	0.82	0.47	0.21	0.22	0.10		
T56-A7	Idle	548	249	17.5	7.9	2.1	1.0	11.5	5.2	0.5	0.2	1.6	0.7
All. TP	Takeoff	2079	943	4.4	2.0	19.3	8.8	0.8	0.4	2.1	1.0	3.7	1.7
	Climbout	1908	865	4.6	2.1	17.6	8.0	0.9	0.4	0.9	0.4	3.0	1.4
	Approach	1053	478	3.7	1.7	7.8	3.5	0.5	0.2	1.1	0.5	3.0	1.4
T53-L-11D	Idle	142	64	4.2	1.9	0.2	0.1	9.0	4.1	0.14	0.06		
(LTC1)	Climbout[i]	679	308	2.0	0.9	5.0	2.3	0.2	0.1	0.68	0.31		
Lyc TS	Approach	679	308	2.0	0.9	5.0	2.3	0.2	0.1	0.68	0.31		
T55-L-11A	Idle			29.5	13.4	0.8	4.0	4.0	1.8				
(LTC4)	Climbout[i]			14.5	6.6	18.6	8.4	0.2	0.1				
Lyc TS	Approach			12.9	5.9	9.1	4.1	0.3	0.1				
T58-GE-5	Idle	133	60	22.5	10.2	0.2	0.1	12.9	5.9	0.1	0.05	0.1	0.05
GE TS	Climbout[i]	886	402	5.0	2.3	6.4	2.9	0.7	0.3	0.9	0.4	0.8	0.4
	Approach	886	402	5.0	2.3	6.4	2.9	0.7	0.3	0.9	0.4	0.8	0.4

[a] Reference 1.

[b] Nitrogen oxides reported as NO_2.

[c] Total hydrocarbons. Volatile organics, including unburned hydrocarbons and organic pyrolysis products.

[d] Sulfur oxides and sulfuric acid reported as SO_2. Calculated from fuel rate and 0.05 wt% sulfur in JP-4 or JP-5 fuel, or 0.01 wt% sulfur in aviation gasoline. For turbine engines, the conversion is therefore SO_x (lb/hr) = 10^{-3} (fuel rate), and for piston engines, the conversion is SO_x (lb/hr) = 2×10^{-4} (fuel rate).

[e] Includes all "condensible particulates," and thus may be much higher than solid particulates alone (except as noted in g below).

[f] "Nom." data are interpolated values assumed for calculational purposes, in the absence of experimental data.

[g] Dry particles only.

[h] For abbreviations, see footnote, Table II-1-2.

[i] "Takeoff" mode is undefined for helicopters.

TABLE II-1-9. EMISSION FACTORS PER AIRCRAFT PER LANDING/TAKEOFF CYCLE–CIVIL AIRCRAFT[a]

Commercial Carrier Aircraft	Power Plant[b]			CO		NO_x[c]		Total HC[d]		SO_x[e]		Particulates	
	No.	Mfg.	Model-Series	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg
Short, Medium, Long Range and Jumbo Jets													
BAC/Aerospatiale Concorde	4	RR	Olymp 593	847.0	384.0	91.0	41.0	246.0	112.0	14.1	6.4		
BAC 111-400	2	RR	Spey 511	103.36	46.88	15.04	6.82	72.42	32.85	1.70	0.77	1.46	0.66
Boeing 707-320B	4	P&W	JT3D-7	262.64	119.12	25.68	11.64	218.24	99.00	4.28	1.94	4.52	2.05
Boeing 727-200	3	P&W	JT8D-17	55.95	25.38	29.64	13.44	13.44	6.09	3.27	1.48	1.17	0.53
Boeing 737-200	2	P&W	JT8D-17	37.30	16.92	19.76	8.96	8.96	4.06	2.18	0.99	0.78	0.35
Boeing 747-200B	4	P&W	JT9D-7	259.64	117.76	83.24	37.76	96.92	43.96	7.16	3.25	5.20	2.36
Boeing 747-200B	4	P&W	JT9D-70	108.92	49.40	107.48	48.76	22.40	10.16	7.96	3.61	5.20	2.36
Boeing 747-200B	4	RR	RB211-524	66.76	30.28	124.9	56.65	10.00	4.54	7.52	3.41		
Lockheed L1011-200	3	RR	RB211-524	50.07	27.71	93.66	42.48	7.50	3.40	5.64	2.56		
Lockheed L1011-100	3	RR	RB211-22B	199.4	90.44	64.29	29.16	138.4	62.77	4.95	2.24		
McDonnell-Douglas DC8-63	4	P&W	JT3D-7	262.64	119.12	25.68	11.64	218.24	99.00	3.27	1.48	1.17	0.53
McDonnell-Douglas DC9-50	2	P&W	JT8D-17	37.30	16.92	19.76	8.96	8.96	4.06	2.18	0.99	0.76	0.35
McDonnell-Douglas DC10-30	3	GE	CF6-50C	116.88	53.01	49.59	22.17	47.10	21.36	4.98	2.26	0.21	0.10
Air Carrier Turboprops – Commuter, Feeder Line and Freighters													
Beech 99	2	PWC	PT6A-28	7.16	3.25	0.82	0.37	5.08	2.30	0.18	0.08		
GD/Convair 580	2	All	501	24.38	11.06	21.66	9.82	9.82	4.45	0.92	0.42		
DeHavilland Twin Otter	2	PWC	PT6A-27	7.16	3.25	0.82	0.37	5.08	2.30	0.18	0.08		
Fairchild F27 and FH227	2	RR	R.Da.7	36.26	16.45	0.92	0.42	22.42	10.17	0.58	0.26		
Grumman Goose	2	PWC	PT6A-27	7.16	3.25	0.82	0.37	5.08	2.30	0.18	0.08		
Lockheed L188 Electra	4	All	501	48.76	22.12	43.32	19.65	19.64	8.91	1.84	0.83		
Lockheed L100 Hercules	4	All	501	48.76	22.12	43.32	19.65	19.64	8.91	1.84	0.83		
Swearingen Metro-2	2	GA	TPE 331-3	6.26	2.84	1.16	0.53	7.68	3.48	0.16	0.07	0.46	0.21

TABLE II-1-9 (CONCLUDED)

General Aviation Aircraft	Power Plant[b] No.	Mfg.	Model-Series	CO lb	CO kg	NO_x[c] lb	NO_x kg	Total HC[d] lb	Total HC kg	SO_x[e] lb	SO_x kg	Particulates lb	Particulates kg
Business Jets													
Cessna Citation	2	P&W	JT15D-1	19.50	8.85	2.00	0.91	6.72	3.05	0.40	0.18		
Dassault Falcon 20	2	GE	CF700-2D	76.14	34.54	1.68	0.76	7.40	3.36	0.78	0.35		
Gates Learjet 24D	2	GE	CJ610-6	88.76	40.26	1.58	0.72	8.42	3.82	0.84	0.38		
Gates Learjet 35, 36	2	GE	TPE 731-2	11.26	5.11	3.74	1.58	3.74	1.70	0.92	0.42		
Rockwell International Shoreliner 75A	2	GE	CF 700	76.14	34.54	1.08	0.76	7.40	3.36	0.78	0.35		
Business Turboprops (EPA Class P2)													
Beech B99 Airliner	2	PWC	PT6A-27	7.16	3.25	0.82	0.37	5.08	2.30	0.18	0.08		
DeHavilland Twin Otter	2	PWC	PT6A-27	7.16	3.25	0.82	0.37	5.08	2.30	0.18	0.08		
Shorts Skyvan-3	2	GA	TPE-331-2	6.44	2.92	0.883	0.400	8.40	3.81	0.16	0.07	0.46	0.21
Swearingen Merlin IIIA	2	GA	TPE-331-3	6.28	2.85	1.15	0.522	7.71	3.50	0.16	0.07	0.46	0.21
General Aviation Piston (EPA Class P1)													
Cessna 150	1	Con	0-200	8.32	3.77	0.02	0.01	0.23	0.10	0.0	0.0		
Piper Warrior	1	Lyc	0-320	14.37	6.52	0.02	0.01	0.26	0.12	0.0	0.0		
Cessna Pressurized Skymaster	2	Con	TS10-360C	33.10	15.01	0.13	0.06	1.15	0.52	0.0	0.0		
Piper Navajo Chieftain	2	Lyc	T10-540	96.24	43.65	0.02	0.01	1.76	0.80	0.0	0.0		

[a] Reference 2.

[b] Abbreviations: All – Detroit Diesel Allison Division of General Motors; Con – Teledyne/Continental; GA – Garrett AiResearch; GE – General Electric; Lyc – Avco/Lycoming; P&W – Pratt & Whitney; PWC – Pratt & Whitney Aircraft of Canada; RR – Rolls Royce.

[c] Nitrogen oxides reported as NO_2.

[d] Total hydrocarbons. Volatile organics, including unburned hydrocarbons and organic pyrolysis products.

[e] Sulfur oxides and sulfuric acid reported as SO_2.

Table II-1-10. EMISSIONS FOR MILITARY AIRCRAFT LANDING/TAKEOFF CYCLES[a]

Aircraft		Power plant No.	Model/Series	TIM[b] code	CO lb	CO kg	NO_x[c] lb	NO_x[c] kg	Total HC[d] lb	Total HC[d] kg	SO_x[e] lb	SO_x[e] kg	Particulates lb	Particulates kg
Fixed Wing - Turbine														
A-4C	Skyhawk	1	J65-W-20	2	16.62	7.54	2.15	0.98	1.10	0.50	0.46	0.21		
A-7	Corsair 2	1	TP30-P-68	2	11.10	5.03	2.05	0.93	3.18	1.44	0.35	0.16		
A-7	Corsair 2	1	TF41-A-2	2	25.79	11.70	4.83	2.19	15.76	7.15	0.52	0.24		
B-52H	Stratofortress	8	TF-33-P-3/5/8	7	504.08	228.65	53.04	24.06	505.76	229.41	10.24	4.64	94.08	42.67
F-4	Phantom 2	2	J79-GE-10	2	32.24	14.62	10.88	4.94	4.94	2.24	1.46	0.66	33.92	15.39
F-5	Freedom Fighter/Tiger	2	J85-GE-21	1	76.64	34.76	2.10	0.95	10.04	4.55	0.76	0.34		
F-14	Tomcat	2	TF30-P-412A	2	39.88	18.09	7.62	3.46	17.36	7.87	1.24	0.56	24.24	11.00
F-15A	Eagle	2	F100-PW-100	1	54.40	24.68	29.96	13.58	2.68	1.22	2.32	1.06	0.44	0.20
F-16	-	1	F100-PW-100	1	27.20	12.34	14.98	6.79	1.34	0.61	1.16	0.53	0.22	0.10
C-5A	Galaxy	4	TF39-GE-1	5	82.12	37.25	79.60	36.11	28.08	12.74	3.84	1.74	4.12	1.87
C-130	Hercules	4	T56-A-7	6	32.36	14.68	9.60	4.35	20.28	9.20	1.60	0.73	4.36	1.98
KC-135	Stratotanker	4	J57-P-22	7	220.92	100.21	24.64	11.18	185.56	84.17	5.36	2.43	31.36	14.22
C-141	Starlifter	4	TF33-P-3/5/7	5	92.40	41.91	19.20	8.71	87.68	39.77	3.00	1.36	33.00	14.97
T-34C	Turbo Mentor	1	PT6A-27	2	1.73	0.73	0.15	0.07	1.27	0.58	0.03	0.01		
T-38	Talon	2	J85-GE-5F	3	82.72	32.99	1.22	0.55	10.42	4.73	0.62	0.28		
P-3C	Orion	4	T56-A-7	6	32.36	14.68	9.60	4.35	20.28	9.20	1.60	0.73	4.36	1.98
S3A	Viking	2	TF34-GE-400	6	34.18	15.50	4.04	1.83	6.44	2.92	1.02	0.46		
Helicopters - Turbine														
UH-1H	Iroquois/Huey	1	T53-L-11D	9	1.55	0.70	1.19	0.54	2.53	1.15	0.20	0.09		
HH-3	Sea King/Jolly Green Giant	2	T58-GE-5	9	13.54	6.14	3.02	1.37	6.78	3.08	0.44	0.20	0.40	0.18
CH-47	Chinook	2	T55-L-11A	9	20.94	9.50	6.68	3.03	2.10	0.95				

[a] Reference 1.
[b] Defined in Table II-1-5.
[c] Nitrogen oxides reported as NO_2.
[d] Total hydrocarbons. Volatile organics, including unburned hydrocarbons and organic pyrolysis products.
[e] Sulfur oxides and sulfuric acid reported as SO_2.

II- 1.3 Modal Emission Rates and Emission Factors per LTO Cycle

The first step in the calculation of aircraft emission factors is the development of a set of modal emission rates. These represent the quantity of pollutant released per unit time in each of the standard modes. Each mode is characterized by an engine power setting (given in Tables II- 1-5 and II- 1-6) and a fuel rate (the quantity of fuel consumed per unit time).

The following procedure is for calculation of aircraft emission factors per LTO cycle, starting with engine modal emission rates:

1) For a specific aircraft, determine the number and model of engines, using for example, Tables II- 1-1 or II- 1-2.

2) Using Table II-1-7 or II- 1-8, locate the appropriate engine data, and prepare a list of modal emission rates for each mode m and pollutant p:

$$\left(\frac{\Delta e}{\Delta t}\right)_{m,p}$$

3) Using known military assignment and mission, or civil aircraft type and application, use Table II- 1-3 or II- 1-4 to select an appropriate set of times-in-mode $(TIM)_m$.

4) For each mode m and pollutant p, multiply the modal emission rate and TIM data for each mode and the sum over all modes. This will yield an emission factor <u>per engine</u>, which must be multiplied by the number of engines, N, to produce the emission factor per LTO cycle, E_p, for an aircraft:

$$E_p = N \Sigma \left(\frac{\Delta e}{\Delta t}\right)_{m,p} \cdot (TIM)_m$$

On a conveniently laid out work sheet, this calculation can be set up easily on a hand calculator with one storage location.

Emission factors calculated in exactly this way are presented in Tables II- 1-9 and II- 1-10.

References for Section II- 1

1. D. R. Sears, <u>Air Pollutant Emission Factors for Military and Civil Aircraft</u>, EPA-450/3-78-117, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, October 1978.

2. R. G. Pace, "Technical Support Report - Aircraft Emission Factors", Office of Mobile Source Air Pollution Control, U.S. Environmental Protection Agency, Ann Arbor, MI, March 1977.

3. Control of Air Pollution for Aircraft and Aircraft Engines, 38 FR 19088, July 17, 1973.

4. M. Platt, et al., The Potential Impact of Aircraft Emissions upon Air Quality, APTD-1085, U.S. Environmental Protection Agency, Research Triangle Park, NC, December 1971.

II-2 Locomotives

II-2.1 General – Railroad locomotives generally follow one of two use patterns: railyard switching or road-haul service. Locomotives can be classified on the basis of engine configuration and use pattern into five categories: 2-stroke switch locomotive (supercharged), 4-stroke switch locomotive, 2-stroke road service locomotive (supercharged), 2-stroke road service locomotive (turbocharged), and 4-stroke road service locomotive.

The engine duty cycle of locomotives is much simpler than many other applications involving diesel internal combustion engines because locomotives usually have only eight throttle positions in addition to idle and dynamic brake. Emission testing is made easier and the results are probably quite accurate because of the simplicity of the locomotive duty cycle.

II-2.2 Emissions – Emissions from railroad locomotives are presented two ways in this section. Table II-2-1 contains average factors based on the nationwide locomotive population breakdown by category. Table II-2-2 gives emission factors by locomotive category on the basis of fuel consumption and on the basis of work output (horsepower hour).

The calculation of emissions using fuel-based emission factors is straightforward. Emissions are simply the product of the fuel usage and the emission factor. In order to apply the work output emission factor, however, an

Table II-2-1. AVERAGE LOCOMOTIVE EMISSION FACTORS BASED ON NATIONWIDE STATISTICS[a]

Pollutant	Average emissions[b]	
	$lb/10^3$ gal	$kg/10^3$ liter
Particulates[c]	25	3.0
Sulfur oxides[d] (SO_x as SO_2)	57	6.8
Carbon monoxide	130	16
Hydrocarbons	94	11
Nitrogen oxides (NO_x as NO_2)	370	44
Aldehydes (as HCHO)	5.5	0.66
Organic acids[c]	7	0.84

[a] Reference 1.
[b] Based on emission data contained in Table II-2-2 and the breakdown of locomotive use by engine category in the United States in Reference 1.
[c] Data based on highway diesel data from Reference 2. No actual locomotive particulate test data are available.
[d] Based on a fuel sulfur content of 0.4 percent from Reference 3.

Table II-2-2. EMISSION FACTORS BY LOCOMOTIVE ENGINE CATEGORY[a]
EMISSION FACTOR RATING: B

Pollutant	Engine category				
	2-Stroke supercharged switch	4-Stroke switch	2-Stroke supercharged road	2-Stroke turbocharged road	4-Stroke road
Carbon monoxide					
$lb/10^3$ gal	84	380	66	160	180
$kg/10^3$ liter	10	46	7.9	19	22
g/hphr	3.9	13	1.8	4.0	4.1
g/metric hphr	3.9	13	1.8	4.0	4.1
Hydrocarbon					
$lb/10^3$ gal	190	146	148	28	99
$kg/10^3$ liter	23	17	18	3.4	12
g/hphr	8.9	5.0	4.0	0.70	2.2
g/metric hphr	8.9	5.0	4.0	0.70	2.2
Nitrogen oxides (NO_x as NO_2)					
$lb/10^3$ gal	250	490	350	330	470
$kg/10^3$ liter	30	59	42	40	56
g/hphr	11	17	9.4	8.2	10
g/metric hphr	11	17	9.4	8.2	10

[a] Use average factors (Table II-2-1) for pollutants not listed in this table.

additional calculation is necessary. Horsepower hours can be obtained using the following equation:

$$w = l\,ph$$

where: w = Work output (horsepower hour)

l = Load factor (average power produced during operation divided by available power)

p = Available horsepower

h = Hours of usage at load factor (l)

After the work output has been determined, emissions are simply the product of the work output and the emission factor. An approximate load factor for a line-haul locomotive (road service) is 0.4; a typical switch engine load factor is approximately 0.06.[1]

References for Section II-2

1. Hare, C.T. and K.J. Springer. Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines. Part 1. Locomotive Diesel Engines and Marine Counterparts. Final Report. Southwest Research Institute. San Antonio, Texas Prepared for the Environmental Protection Agency, Research Triangle Park, N.C., under Contract Number EHA 70-108. October 1972.

2. Young, T.C. Unpublished Data from the Engine Manufacturers Association. Chicago, Ill. May 1970.

3. Hanley, G.P. Exhaust Emission Information on Electro-Motive Railroad Locomotives and Diesel Engines. General Motors Corp. Warren, Mich. October 1971.

II-3 Inboard-Powered Vessels

II-3.1 General – Vessels classified on the basis of use will generally fall into one of three categories: commercial, pleasure, or military. Although usage and population data on vessels are, as a rule, relatively scarce, information on commercial and military vessels is more readily available than data on pleasure craft. Information on military vessels is available in several study reports,[1-5] but data on pleasure craft are limited to sales-related facts and figures.[6-10]

Commercial vessel population and usage data have been further subdivided by a number of industrial and governmental researchers into waterway classifications[11-16] (for example, Great Lakes vessels, river vessels, and coastal vessels). The vessels operating in each of these waterway classes have similar characteristics such as size, weight, speed, commodities transported, engine design (external or internal combustion), fuel used, and distance traveled. The wide variation between classes, however, necessitates the separate assessment of each of the waterway classes with respect to air pollution.

Information on military vessels is available from both the U.S. Navy and the U.S. Coast Guard as a result of studies completed recently. The U.S. Navy has released several reports that summarize its air pollution assessment work.[3-5] Emission data have been collected in addition to vessel population and usage information. Extensive study of the air pollutant emissions from U.S. Coast Guard watercraft has been completed by the U.S. Department of Transportation. The results of this study are summarized in two reports.[1-2] The first report takes an in-depth look at population/usage of Coast Guard vessels. The second report, dealing with emission test results, forms the basis for the emission factors presented in this section for Coast Guard vessels as well as for non-military diesel vessels.

Although a large portion of the pleasure craft in the U.S. are powered by gasoline outboard motors (see section II-4 of this document), there are numerous larger pleasure craft that use inboard power either with or without "out-drive" (an outboard-like lower unit). Vessels falling into the inboard pleasure craft category utilize either Otto cycle (gasoline) or diesel cycle internal combustion engines. Engine horsepower varies appreciably from the small "auxiliary" engine used in sailboats to the larger diesels used in yachts.

II-3.2 Emissions

Commercial vessels. Commercial vessels may emit air pollutants under two major modes of operation: underway and at dockside (auxiliary power).

Emissions underway are influenced by a great variety of factors including power source (steam or diesel), engine size (in kilowatts or horsepower), fuel used (coal, residual oil, or diesel oil), and operating speed and load. Commercial vessels operating within or near the geographic boundaries of the United States fall into one of the three categories of use discussed above (Great Lakes, rivers, coastline). Tables II-3-1 and II-3-2 contain emission information on commercial vessels falling into these three categories. Table II-3-3 presents emission factors for diesel marine engines at various operating modes on the basis of horsepower. These data are applicable to any vessel having a similar size engine, not just to commercial vessels.

Unless a ship receives auxiliary steam from dockside facilities, goes immediately into drydock, or is out of operation after arrival in port, she continues her emissions at dockside. Power must be made available for the ship's lighting, heating, pumps, refrigeration, ventilation, etc. A few steam ships use auxiliary engines (diesel) to supply power, but they generally operate one or more main boilers under reduced draft and lowered fuel rates–a very inefficient process. Motorships (ships powered by internal combustion engines) normally use diesel-powered generators to furnish auxiliary power.[17] Emissions from these diesel-powered generators may also be a source of underway emissions if they are used away from port. Emissions from auxiliary power systems, in terms of the

Table II-3-1. AVERAGE EMISSION FACTORS FOR COMMERCIAL MOTORSHIPS BY WATERWAY CLASSIFICATION
EMISSION FACTOR RATING: C

Emissions[a]	Class[c]		
	River	Great Lakes	Coastal
Sulfur oxides[b] (SO_x as SO_2)			
kg/10^3 liter	3.2	3.2	3.2
lb/10^3 gal	27	27	27
Carbon monoxide			
kg/10^3 liter	12	13	13
lb/10^3 gal	100	110	110
Hydrocarbons			
kg/10^3 liter	6.0	7.0	6.0
lb/10^3 gal	50	59	50
Nitrogen oxides (NO_x as NO_2)			
kg/10^3 liter	33	31	32
lb/10^3 gal	280	260	270

[a]Expressed as function of fuel consumed (based on emission data from Reference 2 and population/usage data from References 11 through 16.

[b]Calculated, not measured. Based on 0.20 percent sulfur content fuel and density of 0.854 kg/liter (7.12 lb/gal) from Reference 17.

[c]Very approximate particulate emission factors from Reference 2 are 470 g/hr (1.04 lb/hr). The reference does not contain sufficient information to calculate fuel-based factors.

quantity of fuel consumed, are presented in Table II-3-4. In some instances, fuel quantities used may not be available, so calculation of emissions based on kilowatt hours (kWh) produced may be necessary. For operating loads in excess of zero percent, the mass emissions (e_l) in kilograms per hour (pounds per hour) are given by:

$$e_l = k l e_f \qquad (1)$$

where: k = a constant that relates fuel consumption to kilowatt hours.[2]

that is, 3.63×10^{-4} 1000 liters fuel/kWh

or

9.59×10^{-5} 1000 gal fuel/kWh

l = the load, kW

e_f = the fuel-specific emission factor from Table 3.2.3-4, kg/10^3 liter (lb/10^3 gal)

Table II-3-2. EMISSION FACTORS FOR COMMERCIAL STEAMSHIPS–ALL GEOGRAPHIC AREAS

EMISSION FACTOR RATING: D

Pollutant	Fuel and operating mode[a]											
	Residual oil[b]						Distillate oil[b]					
	Hoteling		Cruise		Full		Hoteling		Cruise		Full	
	$kg/10^3$ liter	$lb/10^3$ gal	$kg/10^3$ liter	$lb/10^3$ gal	$kg/10^3$ liter	$lb/10^3$ gal	$kg/10^3$ liter	$lb/10^3$ gal	$kg/10^3$ liter	$lb/10^3$ gal	$kg/10^3$ liter	$lb/10^3$ gal
Particulates[c]	1.20[d]	10.0[d]	2.40	20.0	6.78	56.5	1.8	15	1.78	15	1.78	15
Sulfur oxides (SO_x as SO_2)[e]	19.1S	159S	19.1S	159S	19.1S	159S	17.0S	142S	17.0S	142S	17.0S	142S
Carbon monoxide[c]	Neg[d]	Neg[d]	0.414	3.45	0.872	7.27	0.5	4	0.5	4	0.5	4
Hydrocarbons[c]	0.38[d]	3.2[d]	0.082	0.682	0.206	1.72	0.4	3	0.4	3	0.4	3
Nitrogen oxides (NO_x as NO_2)	4.37	36.4	6.70	55.8	7.63	63.6	2.66	22.2	2.83	23.6	5.34	44.5

[a] The operating modes are based on the percentage of maximum available power: "hoteling" is 10 to 11 percent of available power, "full" is 100 percent of available power, and "cruise" is an intermediate power (35 to 75 percent, depending on the test organization and vessel tested).

[b] Test organizations used "Navy Special" fuel oil, which is not a true residual oil. No vessel test data were available for residual oil combustion. "Residual" oil results are from References 2, 3, and 5. "Distillate" oil results are from References 3 and 5 only. Exceptions are noted. "Navy Distillate" was used as distillate test fuel.

[c] Particulate, carbon monoxide, and hydrocarbon emission factors for distillate oil combustion are based on stationary boilers (see Section 1.3 of this document).

[d] Reference 18 indicates that carbon monoxide emitted during hoteling is small enough to be considered negligible. This reference also places hydrocarbons at 0.38 $kg/10^3$ liter (3.2 $lb/10^3$ gal) and particulate at 1.20 $kg/10^3$ liter (10.0 $lb/10^3$ gal). These data are included for completeness only and are not necessarily comparable with other tabulated data.

[e] Emission factors listed are theoretical in that they are based on all the sulfur in the fuel converting to sulfur dioxide. Actual test data from References 3 and 5 confirm the validity of these theoretical factors. "S" is fuel sulfur content in percent.

Table II-3-3. DIESEL VESSEL EMISSION FACTORS BY OPERATING MODE[a]
EMISSION FACTOR RATING: C

Horsepower	Mode	Emissions[b] Carbon monoxide lb/10³ gal		Hydrocarbons lb/10³ gal		Nitrogen oxides (NO_x as NO_2) lb/10³ gal	
		lb/10^3 gal	kg/10^3 liter	lb/10^3 gal	kg/10^3 liter	lb/10^3 gal	kg/10^3 liter
200	Idle	210.3	25.2	391.2	46.9	6.4	0.8
	Slow	145.4	17.4	103.2	12.4	207.8	25.0
	Cruise	126.3	15.1	170.2	20.4	422.9	50.7
	Full	142.1	17.0	60.0	7.2	255.0	30.6
300	Slow	59.0	7.1	56.7	6.8	337.5	40.4
	Cruise	47.3	5.7	51.1	6.1	389.3	46.7
	Full	58.5	7.0	21.0	2.5	275.1	33.0
500	Idle	282.5	33.8	118.1	14.1	99.4	11.9
	Cruise	99.7	11.9	44.5	5.3	338.6	40.6
	Full	84.2	10.1	22.8	2.7	269.2	32.3
600	Idle	171.7	20.6	68.0	8.2	307.1	36.8
	Slow	50.8	6.1	16.6	2.0	251.5	30.1
	Cruise	77.6	9.3	24.1	2.9	349.2	41.8
700	Idle	293.2	35.1	95.8	11.5	246.0	29.5
	Cruise	36.0	4.3	8.8	1.1	452.8	54.2
900	Idle	223.7	26.8	249.1	29.8	107.5	12.9
	2/3	62.2	7.5	16.8	2.0	167.2	20.0
	Cruise	80.9	9.7	17.1	2.1	360.0	43.1
1580	Slow	122.4	14.7	–	–	371.3	44.5
	Cruise	44.6	5.3	–	–	623.1	74.6
	Full	237.7	28.5	16.8	2.0	472.0	5.7
2500	Slow	59.8	7.2	22.6	2.7	419.6	50.3
	2/3	126.5	15.2	14.7	1.8	326.2	39.1
	Cruise	78.3	9.4	16.8	2.0	391.7	46.9
	Full	95.9	11.5	21.3	2.6	399.6	47.9
3600	Slow	148.5	17.8	60.0	7.2	367.0	44.0
	2/3	28.1	3.4	25.4	3.0	358.6	43.0
	Cruise	41.4	5.0	32.8	4.0	339.6	40.7
	Full	62.4	7.5	29.5	3.5	307.0	36.8

[a]Reference 2.
[b]Particulate and sulfur oxides data are not available.

Table II–3-4. AVERAGE EMISSION FACTORS FOR DIESEL-POWERED ELECTRICAL GENERATORS IN VESSELS[a]
EMISSION FACTOR RATING: C

Rated output,[b] kW	Load,[c] % rated output	Emissions: Sulfur oxides (SO_x as SO_2)[d] lb/10³ gal	kg/10³ liter	Carbon monoxide lb/10³ gal	kg/10³ liter	Hydrocarbons lb/10³ gal	kg/10³ liter	Nitrogen oxides (NO_x as NO_2) lb/10³ gal	kg/10³ liter
20	0	27	3.2	150	18.0	263	31.5	434	52.0
	25	27	3.2	79.7	9.55	204	24.4	444	53.2
	50	27	3.2	53.4	6.40	144	17.3	477	57.2
	75	27	3.2	28.5	3.42	84.7	10.2	495	59.3
40	0	27	3.2	153	18.3	584	70.0	214	25.6
	25	27	3.2	89.0	10.7	370	44.3	219	26.2
	50	27	3.2	67.6	8.10	285	34.2	226	27.1
	75	27	3.2	64.1	7.68	231	27.7	233	27.9
200	0	27	3.2	134	16.1	135	16.2	142	17.0
	25	27	3.2	97.9	11.7	33.5	4.01	141	16.9
	50	27	3.2	62.3	7.47	17.8	2.13	140	16.8
	75	27	3.2	26.7	3.20	17.5	2.10	137	16.4
500	0	27	3.2	58.4	7.00	209	25.0	153	18.3
	25	27	3.2	53.4	6.40	109	13.0	222	26.6
	50	27	3.2	48.1	5.76	81.9	9.8	293	35.1
	75	27	3.2	43.7	5.24	59.1	7.08	364	43.6

[a]Reference 2.

[b]Maximum rated output of the diesel-powered generator.

[c]Generator electrical output (for example, a 20 kW generator at 50 percent load equals 10 kW output).

[d]Calculated, not measured, based on 0.20 percent fuel sulfur content and density of 0.854 kg/liter (7.12 lb/gal) from Reference 17.

At zero load conditions, mass emission rates (e_l) may be approximated in terms of kg/hr (lb/hr) using the following relationship:

$$e_l = k l_{rated} e_f \qquad (2)$$

where: k = a constant that relates rated output and fuel consumption,

that is, 6.93×10^{-5} 1000 liters fuel/kW

or

1.83×10^{-5} *1000 gal fuel/kW*

l_{rated} = the rated output, kW

e_f = the fuel-specific emission factor from Table II–3-4, kg/10³ liter (lb/10³ gal)

Pleasure craft. Many of the engine designs used in inboard pleasure craft are also used either in military vessels (diesel) or in highway vehicles (gasoline). Out of a total of 700,000 inboard pleasure craft registered in the United States in 1972, nearly 300,000 were inboard/outdrive. According to sales data, 60 to 70 percent of these inboard/outdrive craft used gasoline-powered automotive engines rated at more than 130 horsepower.[6] The remaining 400,000 pleasure craft used conventional inboard drives that were powered by a variety of powerplants, both gasoline and diesel. Because emission data are not available for pleasure craft, Coast Guard and automotive data[2,19] are used to characterize emission factors for this class of vessels in Table II-3-5.

Military vessels. Military vessels are powered by a wide variety of both diesel and steam power plants. Many of the emission data used in this section are the result of emission testing programs conducted by the U.S. Navy and the U.S. Coast Guard.[1-3,5] A separate table containing data on military vessels is not provided here, but the included tables should be sufficient to calculate approximate military vessel emissions.

TABLE II-3.-5. AVERAGE EMISSION FACTORS FOR INBOARD PLEASURE CRAFT[a]

EMISSION FACTOR RATING: D

Pollutant	Based on fuel consumption				Based on operating time			
	Diesel engine[b]		Gasoline engine[c]		Diesel engine[b]		Gasoline engine[c]	
	kg/10^3 liter	lb/10^3 gal	kg/10^3 liter	lb/10^3 gal	kg/hr	lb/hr	kg/hr	lb/hr
Sulfur oxides[d] (SO_x as SO_2)	3.2	27	0.77	6.4	–	–	0.008	0.019
Carbon monoxide	17	140	149	1240	–	–	1.69	3.73
Hydrocarbons	22	180	10.3	86	–	–	0.117	0.258
Nitrogen oxides (NO_x as NO_2)	41	340	15.7	131	–	–	0.179	0.394

[a]Average emission factors are based on the duty cycle developed for large outboards (≥ 48 kilowatts or ≥ 65 horsepower) from Reference 7. The above factors take into account the impact of water scrubbing of underwater gasoline engine exhaust, also from Reference 7. All values given are for single engine craft and must be modified for multiple engine vessels.
[b]Based on tests of diesel engines in Coast Guard vessels, Reference 2.
[c]Based on tests of automotive engines, Reference 19. Fuel consumption of 11.4 liter/hr (3 gal/hr) assumed. The resulting factors are only *rough* estimates.
[d]Based on fuel sulfur content of 0.20 percent for diesel fuel and 0.043 percent for gasoline from References 7 and 17. Calculated using fuel density of 0.740 kg/liter (6.17 lb/gal) for gasoline and 0.854 kg/liter (7.12 lb/gal) for diesel fuel.

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II-4 Outboard-Powered Vessels

II-4.1 General – Most of the approximately 7 million outboard motors in use in the United States are 2-stroke engines with an average available horsepower of about 25. Because of the predominately leisure-time use of outboard motors, emissions related to their operation occur primarily during nonworking hours, in rural areas, and during the three summer months. Nearly 40 percent of the outboards are operated in the states of New York, Texas, Florida, Michigan, California, and Minnesota. This distribution results in the concentration of a large portion of total nationwide outboard emissions in these states.[1]

II-4.2 Emissions – Because the vast majority of outboards have underwater exhaust, emission measurement is very difficult. The values presented in Table II-4-1 are the approximate atmospheric emissions from outboards. These data are based on tests of four outboard motors ranging from 4 to 65 horsepower.[1] The emission results from these motors are a composite based on the nationwide breakdown of outboards by horsepower. Emission factors are presented two ways in this section: in terms of fuel use and in terms of work output (horsepower hour). The selection of the factor used depends on the source inventory data available. Work output factors are used when the number of outboards in use is available. Fuel-specific emission factors are used when fuel consumption data are obtainable.

Table II-4-1. AVERAGE EMISSION FACTORS FOR OUTBOARD MOTORS[a]
EMISSION FACTOR RATING: B

Pollutant[b]	Based on fuel consumption		Based on work output[c]	
	lb/10^3 gal	kg/10^3 liter	g/hphr	g/metric hphr
Sulfur oxides[d] (SO_x as SO_2)	6.4	0.77	0.49	0.49
Carbon monoxide	3300	400	250	250
Hydrocarbons[e]	1100	130	85	85
Nitrogen oxides (NO_x as NO_2)	6.6	0.79	0.50	0.50

[a] Reference 1. Data in this table are emissions to the atmosphere. A portion of the exhaust remains behind in the water.

[b] Particulate emission factors are not available because of the problems involved with measurement from an underwater exhaust system but are considered negligible.

[c] Horsepower hours are calculated by multiplying the average power produced during the hours of usage by the population of outboards in a given area. In the absence of data specific to a given geographic area, the hphr value can be estimated using average nationwide values from Reference 1. Reference 1 reports the average power produced (not the available power) as 9.1 hp and the average annual usage per engine as 50 hours. Thus, hphr = (number of outboards) (9.1 hp) (50 hours/outboard-year). Metric hphr = 0.9863 hphr.

[d] Based on fuel sulfur content of 0.043 percent from Reference 2 and on a density of 6.17 lb/gal.

[e] Includes exhaust hydrocarbons only. No crankcase emissions occur because the majority of outboards are 2-stroke engines that use crankcase induction. Evaporative emissions are limited by the widespread use of unvented tanks.

References for sections II-4

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II–5 Small, General Utility Engines

II–5.1 General–This category of engines comprises small 2-stroke and 4-stroke, air-cooled, gasoline-powered motors. Examples of the uses of these engines are: lawnmowers, small electric generators, compressors, pumps, minibikes, snowthrowers, and garden tractors. This category does *not* include motorcycles, outboard motors, chain saws, and snowmobiles, which are either included in other parts of this chapter or are not included because of the lack of emission data.

Approximately 89 percent of the more than 44 million engines of this category in service in the United States are used in lawn and garden applications.[1]

II–5.2 Emissions–Emissions from these engines are reported in Table II–5-1. For the purpose of emission estimation, engines in this category have been divided into lawn and garden (2-stroke), lawn and garden (4-stroke), and miscellaneous (4-stroke). Emission factors are presented in terms of horsepower hours, annual usage, and fuel consumption.

References for Section II–5

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Table II-5-1. EMISSION FACTORS FOR SMALL, GENERAL UTILITY ENGINES[a,b]
EMISSION FACTOR RATING: B

Engine	Sulfur oxides[c] (SO_x as SO_2)	Particulate	Carbon monoxide	Hydrocarbons Exhaust	Hydrocarbons Evaporative[d]	Nitrogen oxides (NO_x as NO_2)	Alde-hydes (HCHO)
2-Stroke, lawn and garden							
g/hphr	0.54	7.1	486	214	–	1.58	2.04
g/metric hphr	0.54	7.1	486	214	–	1.58	2.04
g/gal of fuel	1.80	23.6	1,618	713	–	5.26	6.79
g/unit-year	38	470	33,400	14,700	113	108	140
4-Stroke, lawn and garden							
g/hphr	0.37	0.44	279	23.2	–	3.17	0.49
g/metric hphr	0.37	0.44	279	23.2	–	3.17	0.49
g/gal of fuel	2.37	2.82	1,790	149	–	20.3	3.14
g/unit-year	26	31	19,100	1,590	113	217	34
4-Stroke miscellaneous							
g/hphr	0.39	0.44	250	15.2	–	4.97	0.47
g/metric hphr	0.39	0.44	250	15.2	–	4.97	0.47
g/gal of fuel	2.45	2.77	1,571	95.5	–	31.2	2.95
g/unit-year	30	34	19,300	1,170	290	384	36

[a]Reference 2.

[b]Values for g/unit-year were calculated assuming an annual usage of 50 hours and a 40 percent load factor. Factors for g/hphr can be used in instances where annual usages, load factors, and rated horsepower are known. Horsepower hours are the product of the usage in hours, the load factor, and the rated horsepower.

[c]Values calculated, not measured, based on the use of 0.043 percent sulfur content fuel.

[d]Values calculated from annual fuel consumption. Evaporative losses from storage and filling operations are not included (see Chapter 4).

II-6 Agricultural Equipment

II-6.1 General – Farm equipment can be separated into two major categories: wheeled tractors and other farm machinery. In 1972, the wheeled tractor population on farms consisted of 4.5 million units with an average power of approximately 34 kilowatts (45 horsepower). Approximately 30 percent of the total population of these tractors is powered by diesel engines. The average diesel tractor is more powerful than the average gasoline tractor, that is, 52 kW (70 hp) versus 27 kW (36 np).[1] A considerable amount of population and usage data is available for farm tractors. For example, the Census of Agriculture reports the number of tractors in use for each county in the U.S.[2] Few data are available on the usage and numbers of non-tractor farm equipment, however. Self-propelled combines, forage harvesters, irrigation pumps, and auxiliary engines on pull-type combines and balers are examples of non-tractor agricultural uses of internal combustion engines. Table II-6-1 presents data on this equipment for the U.S.

II-6.2 Emissions – Emission factors for wheeled tractors and other farm machinery are presented in Table II-6-2. Estimating emissions from the time-based emission factors—grams per hour (g/hr) and pounds per hour (lb/hr)—requires an average usage value in hours. An approximate figure of 550 hours per year may be used or, on the basis of power, the relationship, usage in hours = 450 + 5.24 (kW - 37.2) or usage in hours = 450 + 3.89 (hp - 50) may be employed.[1]

The best emissions estimates result from the use of "brake specific" emission factors (g/kWh or g/hphr). Emissions are the product of the brake specific emission factor, the usage in hours, the power available, and the load factor (power used divided by power available). Emissions are also reported in terms of fuel consumed.

Table II-6-1. SERVICE CHARACTERISTICS OF FARM EQUIPMENT (OTHER THAN TRACTORS)[a]

Machine	Units in service, x10^3	Typical size	Typical power		Percent gasoline	Percent diesel
			kW	hp		
Combine, self-propelled	434	4.3 m (14 ft)	82	110	50	50
Combine, pull type	289	2.4 m (8 ft)	19	25	100	0
Corn pickers and picker-shellers	687	2-row	–[b]	–	–	–
Pick-up balers	655	5400 kg/hr (6 ton/hr)	30	40	100	0
Forage harvesters	295	3.7 m (12 ft) or 3-row	104	140	0	100
Miscellaneous	1205	–	22	30	50	50

[a]Reference 1.

[b]Unpowered.

Table II-6-2. EMISSION FACTORS FOR WHEELED FARM TRACTORS AND NON-TRACTOR AGRICULTURAL EQUIPMENT[a]
EMISSION FACTOR RATING: C

Pollutant	Diesel farm tractor	Gasoline farm tractor	Diesel farm equipment (non-tractor)	Gasoline farm equipment (non-tractor)
Carbon monoxide				
g/hr	161	3,380	95.2	4,360
lb/hr	0.355	7.46	0.210	9.62
g/kWh	4.48	192	5.47	292
g/hphr	3.34	143	4.08	218
$kg/10^3$ liter	14.3	391	16.7	492
$lb/10^3$ gal	119	3,260	139	4,100
Exhaust hydrocarbons				
g/hr	77.8	128	38.6	143
lb/hr	0.172	0.282	0.085	0.315
g/kWh	2.28	7.36	2.25	9.63
g/hphr	1.70	5.49	1.68	7.18
$kg/10^3$ liter	7.28	15.0	6.85	16.2
$lb/10^3$ gal	60.7	125	57.1	135
Crankcase hydrocarbons[b]				
g/hr	–	26.0	–	28.6
lb/hr	–	0.057	–	0.063
g/kWh	–	1.47	–	1.93
g/hphr	–	1.10	–	1.44
$kg/10^3$ liter	–	3.01	–	3.25
$lb/10^3$ gal	–	25.1	–	27.1
Evaporative hydrocarbons[b]				
g/unit-year	–	15,600	–	1,600
lb/unit-year	–	34.4	–	3.53
Nitrogen oxides (NO_x as NO_2)				
g/hr	452	157	210	105
lb/hr	0.996	0.346	0.463	0.231
g/kWh	12.6	8.88	12.11	7.03
g/hphr	9.39	6.62	9.03	5.24
$kg/10^3$ liter	40.2	18.1	36.8	11.8
$lb/10^3$ gal	335	151	307	98.5
Aldehydes (RCHO as HCHO)				
g/hr	16.3	7.07	7.23	4.76
lb/hr	0.036	0.016	0.016	0.010
g/kWh	0.456	0.402	0.402	0.295
g/hphr	0.340	0.300	0.30	0.220
$kg/10^3$ liter	1.45	0.821	1.22	0.497
$lb/10^3$ gal	12.1	6.84	10.2	4.14
Sulfur oxides[c] (SO_x as SO_2)				
g/hr	42.2	5.56	21.7	6.34
lb/hr	0.093	0.012	0.048	0.014

Table II-6-2. (continued). EMISSION FACTORS FOR WHEELED FARM TRACTORS AND NON-TRACTOR AGRICULTURAL EQUIPMENT[a]
EMISSION FACTOR RATING: C

Pollutant	Diesel farm tractor	Gasoline farm tractor	Diesel farm equipment (non-tractor)	Gasoline farm equipment (non-tractor)
g/kWh	1.17	0.312	1.23	0.377
g/hphr	0.874	0.233	0.916	0.281
$kg/10^3$ liter	3.74	0.637	3.73	0.634
$lb/10^3$ gal	31.2	5.31	31.1	5.28
Particulate				
g/hr	61.8	8.33	34.9	7.94
lb/hr	0.136	0.018	0.077	0.017
g/kWh	1.72	0.471	2.02	0.489
g/hphr	1.28	0.361	1.51	0.365
$kg/10^3$ liter	5.48	0.960	6.16	0.823
$lb/10^3$ gal	45.7	8.00	51.3	6.86

[a]Reference 1.

[b]Crankcase and evaporative emissions from diesel engines are considered negligible.

[c]Not measured. Calculated from fuel sulfur content of 0.043 percent and 0.22 percent for gasoline-powered and diesel-powered equipment, respectively.

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2. County Farm Reports. U.S. Census of Agriculture. U.S. Department of Agriculture. Washington, D.C.

II-7 Heavy-Duty Construction Equipment

II-7.1 General - The useful life of construction equipment is fairly short because of the frequent and severe usage it must endure. The annual usage of the various categories of equipment considered here ranges from 740 hours (wheeled tractors and rollers) to 2000 hours (scrapers and off-highway trucks). This high level of use results in average vehicle lifetimes of only 6 to 16 years. The equipment categories in this section include: track type tractors, track type loaders, motor graders, wheel tractor scrapers, off-highway trucks (includes pavement cold planers and wheel dozers), wheeled loaders, wheeled tractors, rollers (static and vibratory), and miscellaneous machines. The latter category contains an array of less numerous mobile and semi-mobile machines used in construction such as log skidders, hydraulic excavators/crawlers, trenchers, concrete pavers, compact loaders, crane lattice booms, cranes, hydraulic excavator wheels, and bituminous pavers. Some of these categories are different from the Third Edition.

II-7.2 Emissions - Recently, Environmental Research and Technology, Inc. prepared a report[3] under the sponsorship of a consortium of industry groups. This report, referred to as the CAL/ERT report, provided a very comprehensive investigation of farm construction and industrial equipment emissions. The emissions of twenty different types of construction equipments are grouped roughly according to the categories in the Third Edition by their populations in California (based on a report prepared by the California Air Resources Board[4]). The updated emission factors on $HC/CO/NO_x$ for heavy-duty construction equipment for diesel engines are reported in Table II-7.1. No update has been done on other emissions (aldehydes, sulfur oxides, and particulates), and their values are carried over from the Third Edition. Less than five percent of the sales use gasoline engines, and the trend is toward complete dieselization. No update has been done on the gasoline engine construction equipment emissions. Therefore, the emission factors for gasoline engines from the Third Edition are reprinted in Table II-7.2. The factors are reported in three different forms-on the basis of running time, fuel consumed, and power consumed.

In order to estimate emissions from time-based emission factors, annual equipment usage in hours must be estimated. The following estimates of use for the equipment listed in the tables should permit reasonable emission calculations.

Category	Annual operation, hours/year
Tracklaying tractors	1050
Tracklaying shovel loaders	1100
Motor graders	830
Scrapers	2000
Off-highway trucks	4000
(including wheeled dozers)	2000
Wheeled loaders	1140
Wheeled tractors	740
Rollers	740
Miscellaneous	1000

The best method for calculating emissions, however, is on the basis of "brake specific" emission factors (g/kWh or g/hphr). Emissions are calculated by taking the product of the brake specific emission factor, the usage in hours, the power available (that is, rated power), and the load factor (the power actually used divided by the power available).

References for Section II-7

1. Hare, C.T. and K.J. Springer. Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines-Final Report. Part 5: Heavy-Duty Farm, Construction, and Industrial Engines. Southwest Research Institute, San Antonio, Tex. Prepared for Environmental Protection Agency, Research Triangle Park, N.C., under Contract No. EHS 70-108. October 1973. 105p.

2. Hare, C.T. Letter to C.C. Masser of Environmental Protection Agency, Research Triangle Park, N.C., concerning fuel-based emission rates for farm, construction, and industrial engines. San Antonio, Tex. January 14, 1974. 4p.

3. Ingalls, Melvin N. Recommended Revisions to Gaseous Emission Factors from Several Classes of Off-Highway Mobile Sources--Final Report. Southwest Research Institute, San Antonio, Texas. Prepared for Environmental Protection Agency, Office of Mobile Source Air Pollution Control, Ann Arbor, MI., under Contract NO. 68-03-3162 September 1984.

4. State of California Air Resources Board. Status Report: Emissions Inventory on Non-Farm (MS-1), Farm (MS-2), and Lawn and Garden (Utility) (MS-3) Equipment. July 1983. 87p.

Table II-7.1 Emission Factors for Heavy-Duty, Diesel-Powered Construction Equipment[a]
Emission Factor Rating: C

Pollutant	Track-type tractor	Wheeled tractor	Wheeled dozer[b]	Scraper	Motor grader
CARBON MONOXIDE					
g/hr	157.01	1622.77		568.19	68.46
lb/hr	0.346	3.59		1.257	0.151
g/kWh	2.88	9.84		3.28	2.06
g/hphr	2.15	7.34		2.45	1.54
$kg/10^3$ liter	9.4	32.19		10.16	6.55
$lb/10^3$ gal	78.5	268.5		84.6	54.65
EXHAUST HYDROCARBONS					
g/hr	55.06	85.26		128.15	18.07
lb/hr	0.121	0.188		0.282	0.040
g/kWh	1.01	2.36		0.74	0.48
g/hphr	0.75	1.76		0.55	0.36
$kg/10^3$ liter	3.31	7.74		2.28	1.53
$lb/10^3$ gal	27.6	64.6		19.0	12.73
NITROGEN OXIDES (NO_x as NO_2)					
g/hr	570.70	575.84		1740.74	324.43
lb/hr	1.26	1.269		3.840	0.713
g/kWh	10.47	15.96		10.00	9.57
g/hphr	7.81	11.91		7.46	7.14
$kg/10^3$ liter	34.16	52.35		30.99	30.41
$lb/10^3$ gal	284.92	436.67		258.6	253.84
ALDEHYDES (RCHO as HCHO)					
g/hr	12.4	13.5	29.5	65.	5.54
lb/hr	0.027	0.030	0.065	0.143	0.012
g/kWh	0.228	0.378	0.215	0.375	0.162
g/hphr	0.170	0.282	0.160	0.280	0.121
$kg/10^3$ liter	0.745	1.23	0.690	1.16	0.517
$lb/10^3$ gal	6.22	10.3	5.76	9.69	4.31
SULFUR OXIDES (SO_x as SO_2)					
g/hr	62.3	40.9	158.	210.	39.0
lb/hr	0.137	0.090	0.348	0.463	0.086
g/kWh	1.14	1.14	1.16	1.21	1.17
g/hphr	0.851	0.851	0.867	0.901	0.874
$kg/10^3$ liter	3.73	3.73	3.74	3.74	3.73
$lb/10^3$ gal	31.1	31.1	31.2	31.2	31.1
PARTICULATE					
g/hr	50.7	61.5	75.	184.	27.7
lb/hr	0.112	0.136	0.165	0.406	0.061
g/kWh	0.928	1.70	0.551	1.06	0.838
g/hphr	0.692	1.27	0.411	0.789	0.625
$kg/10^3$ liter	3.03	5.57	1.77	3.27	2.66
$lb/10^3$ gal	25.3	46.5	14.8	27.3	22.2

[a] References 3 and 4 for the HC/CO/NO_x emissions, and references 1 and 2 for other emissions.

[b] The wheeled dozer HC/CO/NO_x emissions are included in the off-highway truck category.

Table II-7.1 (cont'd) Emission Factors for Heavy-Duty Diesel-Powered Construction Equipment[a]
Emission Factor Rating: C

Pollutant	Wheeled loader	Tracktype loader	Off-Highway truck[b]	Roller	Miscel-laneous
CARBON MONOXIDE					
g/hr	259.58	91.15	816.81	137.97	306.37
lb/hr	0.572	0.201	1.794	0.304	0.675
g/kWh	3.63	3.03	4.70	8.08	6.16
g/hphr	2.71	2.26	2.28	6.03	4.60
$kg/10^3$ liter	11.79	9.93	14.73	22.64	18.41
$lb/10^3$ gal	98.66	82.85	123.46	188.37	153.51
EXHAUST HYDROCARBONS					
g/hr	113.17	44.55	86.84	30.58	69.35
lb/hr	0.25	0.098	0.192	0.067	0.152
g/kWh	1.59	1.49	0.50	1.30	1.35
g/hphr	0.97	1.11	0.37	0.97	1.01
$kg/10^3$ liter	5.17	4.85	1.58	3.60	4.04
$lb/10^3$ gal	43.16	40.55	13.16	30.09	33.70
NITROGEN OXIDES (NO_x as NO_2)					
g/hr	858.19	375.22	1889.16	392.90	767.30
lb/hr	1.89	0.827	4.166	0.862	1.691
g/kWh	11.81	12.46	10.92	17.49	14.75
g/hphr	8.81	9.30	8.15	13.05	11.01
$kg/10^3$ liter	38.5	40.78	34.29	48.49	44.10
$lb/10^3$ gal	321.23	339.82	286.10	404.51	368.01
ALDEHYDES (RCHO as HCHO)					
g/hr	18.8	4.00	51.0	7.43	13.9
lb/hr	0.041	0.009	0.112	0.016	0.031
g/kWh	0.264	0.134	0.295	0.263	0.272
g/hphr	0.197	0.100	0.220	0.196	0.203
$kg/10^3$ liter	0.859	0.439	0.928	0.731	0.813
$lb/10^3$ gal	7.17	3.66	7.74	6.10	6.78
SULFUR OXIDES (SO_x as SO_2)					
g/hr	82.5	34.4	206.	30.5	64.7
lb/hr	0.182	0.076	0.454	0.067	0.143
g/kWh	1.15	1.14	1.19	1.34	1.25
g/hphr	0.857	0.853	0.887	1.00	0.932
$kg/10^3$ liter	3.74	3.74	3.74	3.73	3.73
$lb/10^3$ gal	31.2	31.2	31.2	31.1	31.1
PARTICULATE					
g/hr	77.9	26.4	116.	22.7	63.2
lb/hr	0.172	0.058	0.256	0.050	0.139
g/kWh	1.08	0.878	0.673	1.04	1.21
g/hphr	0.805	0.655	0.502	0.778	0.902
$kg/10^3$ liter	3.51	2.88	2.12	2.90	3.61
$lb/10^3$ gal	29.3	24.0	17.7	24.2	30.1

[a] References 3 and 4 for the HC/CO/NO_x emissions and references 1 and 2 for other emissions.

[b] The off-highway truck category incudes HC/CO/NO_x emissions from the wheeled dozer.

Table II-7.2 Emission Factors for Heavy-Duty, Gasoline-Powered Construction Equipment[a]
Emission Factor Rating: C

Pollutant	Wheeled tractor	Motor grader	Wheeled loader	Roller	Miscel-laneous
CARBON MONOXIDE					
g/hr	4320.	5490.	7060.	6080.	7720.
lb/hr	9.52	12.1	15.6	13.4	17.0
g/kWh	190.	251.	219.	271.	266.
g/hphr	142.	187.	163.	202	198.
kg/10^3 liter	389.	469.	435.	460.	475.
lb/10^3 gal	3250.	3910.	3630.	3840.	3960.
EXHAUST HYDROCARBONS					
g/hr	164.	186.	241.	277.	254.
lb/hr	0.362	0.410	0.531	0.611	0.560
g/kWh	7.16	8.48	7.46	12.40	8.70
g/hphr	5.34	6.32	5.56	9.25	6.49
kg/10^3 liter	14.6	15.8	14.9	21.1	15.6
lb/10^3 gal	122.	132.	124.	176.	130.
EVAPORATIVE HYDROCARBONS[b]					
g/hr	30.9	30.0	29.7	28.2	25.4
lb/hr	0.0681	0.0661	0.0655	0.0622	0.0560
CRANKCASE HYDROCARBONS[b]					
g/hr	32.6	37.1	48.2	55.5	50.7
lb/hr	0.0719	0.0818	0.106	0.122	0.112
NITROGEN OXIDES (NO_x as NO_2)					
g/hr	195.	145.	235.	164.	187.
lb/hr	0.430	0.320	0.518	0.362	0.412
g/kWh	8.54	6.57	7.27	7.08	6.48
g/hphr	6.37	4.90	5.42	5.28	4.79
kg/10^3 liter	17.5	12.2	14.5	12.0	11.5
lb/10^3 gal	146.	102.	121.	100.	95.8
ALDEHYDES (RCHO as HCHO)					
g/hr	7.97	8.80	9.65	7.57	9.00
lb/hr	0.0176	0.0194	0.0213	0.0167	0.0198
0.0198					
g/kWh	0.341	0.386	0.298	0.343	0.298
g/hphr	0.254	0.288	0.222	0.256	0.222
kg/10^3 liter	0.697	0.721	0.593	0.582	0.532
lb/10^3 gal	5.82	6.02	4.95	4.86	4.44
SULFUR OXIDES (SO_x as SO_2)					
g/hr	7.03	7.59	10.6	8.38	10.6
lb/hr	0.0155	0.0167	0.0234	0.0185	0.0234
g/kWh	0.304	0.341	0.319	0.373	0.354
g/hphr	0.227	0.254	0.238	0.278	0.264
kg/10^3 liter	0.623	0.636	0.636	0.633	0.633
lb/10^3 gal	5.20	5.31	5.31	5.28	5.28

Table II-7.2 (cont'd) Emission Factors for Heavy-Duty, Gasoline-Powered Construction Equipment[a]
Emission Factor Rating: C

Pollutant	Wheeled tractor	Motor grader	Wheeled loader	Roller	Miscel- laneous
PARTICULATE					
g/hr	10.9	9.40	13.5	11.8	11.7
lb/hr	0.0240	0.0207	0.0298	0.0260	0.0258
g/kWh	0.484	0.440	0.421	0.527	0.406
g/hphr	0.361	0.328	0.314	0.393	0.303
kg/10^3 liter	0.991	0.822	0.839	0.895	0.726
lb/10^3 gal	8.27	6.86	7.00	7.47	6.06

[a] References 1 and 2.

[b] Evaporative and crankcase hydrocarbons based on operating time only (Reference 1).

II-8 Snowmobiles

II-8.1 General – In order to develop emission factors for snowmobiles, mass emission rates must be known, and operating cycles representative of usage in the field must be either known or assumed. Extending the applicability of data from tests of a few vehicles to the total snowmobile population requires additional information on the composition of the vehicle population by engine size and type. In addition, data on annual usage and total machine population are necessary when the effect of this source on national emission levels is estimated.

An accurate determination of the number of snowmobiles in use is quite easily obtained because most states require registration of the vehicles. The most notable features of these registration data are that almost 1.5 million sleds are operated in the United States, that more than 70 percent of the snowmobiles are registered in just four states (Michigan, Minnesota, Wisconsin, and New York), and that only about 12 percent of all snowmobiles are found in areas outside the northeast and northern midwest.

II-8.2 Emissions – Operating data on snowmobiles are somewhat limited, but enough are available so that an attempt can be made to construct a representative operating cycle. The required end products of this effort are time-based weighting factors for the speed/load conditions at which the test engines were operated; use of these factors will permit computation of "cycle composite" mass emissions, power consumption, fuel consumption, and specific pollutant emissions.

Emission factors for snowmobiles were obtained through an EPA-contracted study[1] in which a variety of snowmobile engines were tested to obtain exhaust emissions data. These emissions data along with annual usage data were used by the contractor to estimate emission factors and the nationwide emission impact of this pollutant source.

To arrive at average emission factors for snowmobiles, a reasonable estimate of average engine size was necessary. Weighting the size of the engine to the degree to which each engine is assumed to be representative of the total population of engines in service resulted in an estimated average displacement of 362 cubic centimeters (cm^3).

The speed/load conditions at which the test engines were operated represented, as closely as possible, the normal operation of snowmobiles in the field. Calculations using the fuel consumption data obtained during the tests and the previously approximated average displacement of 362 cm^3 resulted in an estimated average fuel consumption of 0.94 gal/hr.

To compute snowmobile emission factors on a gram per unit year basis, it is necessary to know not only the emission factors but also the annual operating time. Estimates of this usage are discussed in Reference 1. On a national basis, however, average snowmobile usage can be assumed to be 60 hours per year. Emission factors for snowmobiles are presented in Table II-8-1.

References for Section II-8

1. Hare, C. T. and K. J. Springer. Study of Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines. Final Report. Part 7: Snowmobiles. Southwest Research Institute, San Antonio, Tex. Prepared for Environmental Protection Agency, Research Triangle Park, N.C., under Contract No. EHS 70-108. April 1974.

Table II-8-1. EMISSION FACTORS FOR SNOWMOBILES
EMISSION FACTOR RATING: B

Pollutant	Emissions			
	g/unit-year[a]	g/gal[b]	g/liter[b]	g/hr[b]
Carbon monoxide	58,700	1,040.	275.	978.
Hydrocarbons	37,800	670.	177.	630.
Nitrogen oxides	600	10.6	2.8	10.0
Sulfur oxides[c]	51	0.90	0.24	0.85
Solid particulate	1,670	29.7	7.85	27.9
Aldehydes (RCHO)	552	9.8	2.6	9.2

[a]Based on 60 hours of operation per year and 362 cm^3 displacement.

[b]Based on 362 cm^3 displacement and average fuel consumption of 0.94 gal/hr.

[c]Based on sulfur content of 0.043 percent by weight.

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